Dry sliding wear research on C45 carbon steel, 41Cr4 alloyed steel and X3CrNi13-4 martensitic stainless steel

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Abstract. In this paper, the experimental research refers to the dry sliding wear behaviour of three type of steels namely carbon steel (C45), alloyed steel (41Cr4) and martensitic stainless steel (X3CrNi13-4). From the X3CrNi13-4 martensitic stainless steel, three different batches with varying percentages of chromium and nickel were analyzed. For all the steels, the research was made using a tribometer (CSM Tribometer) through to the pin-on-disk method (POD), where the friction coefficient and wear rate were determined. All these tests were made according to the ASTM G99 standard, with the same working conditions for all five samples, only for the two batches of the X3CrNi13-4 steel, the motor speed was varied. The obtained results were presented through characteristic graphs for the friction coefficient and through images acquired with a digital and a laser microscope respectively with a specialized software regarding the wear track profiles. It can be concluded that the C45 carbon steel showed the good tribological behaviour with the highest dry sliding wear resistance.

1. Introduction

As a type of wear, sliding wear can occur in many industrial applications which can be part especially of the automotive and energy industry [1-9]. For example in Hydro Power Plants (HPPs) where hydraulic machines operate, beside the abrasive, adhesive, erosion wear (hydro-abrasion / cavitation erosion) respectively corrosion, the sliding wear is also present. For example, for the radial bearing, crank or pin crank of a Kaplan turbine respectively for the needle spear of a Pelton turbine, the sliding wear is the wear mechanism [10-23].

Due to the dynamic interaction of the mating components, also regardless of the materials from which they are manufactured and respectively the operating environment, different components can be more or less affected by sliding wear. Depending on the material properties and also depending of the used materials pairs, the sliding wear resistance can be high or low [24-35].

Different materials like metallic materials (iron alloys) and non-metallic materials can be used for manufacturing of machine parts in the industry. In this regard, it is fundamental to evaluate the resistance of these materials, resistance which can be estimated by testing the materials with professional apparatus [36-47].
The Fe alloys, due to their alloying elements, can possess good mechanical properties. Many studies have been conducted with regard to investigate the carbon steels, alloyed steels and stainless steels. For example, samples of C45 carbon steels, 41Cr4 alloyed steels and respectively X3CrNi13-4 martensitic stainless steels have been tested by several authors were investigated for their wear and corrosion resistance and it was found out that some steels which have a good wear resistance can have a poor corrosion resistance and vice versa. Also, martensitic stainless steels which widely are used in industrial processes due to their excellent mechanical properties and corrosion resistance in various media, are continuously investigated [48-52].

Regarding their sliding wear resistance of these steels mentioned above it can be concluded that this is strongly affected by increasing the parameters values of the testing machine (a tribometer or a tester) especially like applied load and sliding speed. On the other hand, through a higher carbon content and by applying different treatments, the sliding wear behaviour of the materials can be also improved [53-55].

In this regard, also this paper is dedicated to present and to compare the experimental results (by means of friction coefficient and wear rate) of the dry sliding wear research on a C45 carbon steel, a 41Cr4 alloyed steel and an three different batches with varying percentages of chromium and nickel of the X3CrNi13-4 martensitic stainless steel, all this by using a tribometer through to the pin-on-disk method with the experimental procedure described below and with the authors knowledge in the term of wear from preview studies.

2. Experimental procedure

Dry sliding wear research was done by using a tribometer (CSM Instruments) through to the pin-on-disk method (POD). For the tested samples the counterpart was a 100Cr6 steel ball (6 mm in diameter) introduced in a pin holder. According to the ASTM G99 Standard [56], the temperature was set at 20°C and the atmosphere environment was the air with the humidity set to 50%. Before and after the tests, the samples (with dimensions Φ 16 x 10 mm) and the counterparts were cleaned with acetone.

The applied load was set only at 10 N and the sliding distance was stop at 500 m. The other main parameters for this dry sliding wear research are shown in Table 1.

| Samples              | Sliding speed (mm s⁻¹) | Motor speed (rpm) | Radius (mm) | Test duration (s) |
|----------------------|------------------------|-------------------|-------------|-------------------|
| C45                  | 170                    | 400               | 4.05        | 2940              |
| 41Cr4                | 170                    | 400               | 4.06        | 2940              |
| X3CrNi13-4 (1)       | 191.2                  | 450               | 4.06        | 2620              |
| X3CrNi13-4 (2)       | 170                    | 400               | 4.06        | 2940              |
| X3CrNi13-4 (3)       | 148.8                  | 350               | 4.06        | 3370              |

By using the tribometer software (InstrumX) with an acquisition rate of 10 Hz, the friction coefficient was registered as graphic representation for all the tests and regarding the wear rate, this was calculated with the help of equation 1 [56]:

\[
K = \frac{2\pi \cdot h \left(3h^2 + 4s^2\right)}{6 \cdot L \cdot d \cdot s}
\]

where: \(K\) is the wear rate; \(h\) – the wear track depth; \(s\) – the wear track width; \(L\) – the applied load and \(d\) is the sliding distance, which is only for 500 m.

Also, for the results exposure the samples mass was measured by weighing before and after the tests with the help of a Sartorius digital balance.
The chemical composition of the tested samples (C45 as a carbon steel, 41Cr4 as an alloyed steel (which was typical heat treated for armament industry) and X3CrNi13-4 as martensitic stainless steel in three different batches) is reported in Table 2.

Table 2. The chemical composition of the tested samples (wt.%)  

| Samples          | C   | Si   | Mn   | P    | S    | Cu  | Ni  | Cr  | Mo  | Fe  |
|------------------|-----|------|------|------|------|-----|-----|-----|-----|-----|
| C45              | 0.47| 0.24 | 0.68 | 0.010| 0.004| 0.14| 0.09| 0.14| 0.01| 97.49|
| 41Cr4            | 0.394| 0.202| 0.59 | 0.005| 0.016| 0.23| 0.272| 0.95| 0.03| 97.17|
| X3CrNi13-4 (1)   | 0.07| 0.41 | 0.56 | 0.027| 0.014| 0.16| 5.17| 11.15| 0.35| 82.08|
| X3CrNi13-4 (2)   | 0.05| 0.62 | 0.65 | 0.021| 0.012| 0.25| 3.62| 12.95| 0.36| 81.46|
| X3CrNi13-4 (3)   | 0.06| 0.43 | 0.42 | 0.015| 0.009| 0.07| 3.81| 12.5 | 0.32| 82.36|

3. Results and discussions
The friction coefficient evolution for the five tested samples is shown in Figure 1.

![Figure 1. Friction coefficient evolution vs time (s) and distance (m) for a) C45, b) 41Cr4, c) X3CrNi13-4 (1), d) X3CrNi13-4 (2) and e) X3CrNi13-4 (3)]
The friction coefficient reach values between 0.50 - 0.90 for all samples. For the C45 and 41Cr4 samples, the values are the lowest and for the X3CrNi13-4, the values are among the highest and their curves are almost the same. It can be seen that the materials pair (C45 with 100Cr6 counterpart) has the best tribological behaviour and after 100 m the steady state [57] is reached between the values 0.62 - 0.70 with small deviations compared to the other curves (Figures 1 b), c), d) and e).

For a better comparison between the friction coefficient evolutions of the samples, in Table 3 the main friction coefficient values are shown (it can see that the lowest mean value belongs to C45 steel).

| Samples            | Start | Min   | Max   | Mean | Std. Dev. |
|--------------------|-------|-------|-------|------|-----------|
| C45                | 0.193 | 0.177 | 0.712 | 0.673| 0.039     |
| 41Cr4              | 0.202 | 0.202 | 0.832 | 0.785| 0.041     |
| X3CrNi13-4 (1)     | 0.163 | 0.152 | 0.863 | 0.827| 0.042     |
| X3CrNi13-4 (2)     | 0.216 | 0.206 | 0.873 | 0.827| 0.030     |
| X3CrNi13-4 (3)     | 0.205 | 0.205 | 0.920 | 0.851| 0.037     |

Furthermore, through images acquired with a digital and with a confocal 3D laser scanning microscope (Keyence), the wear track of the 100Cr6 counterparts and of the samples are shown in Figure 2 respectively in Figure 3 and Figure 4.

Figure 2. 100Cr6 counterparts wear track (magnification 100 X – 500 µm) for a) C45, b) 41Cr4, c) X3CrNi13-4 (1), d) X3CrNi13-4 (2) and e) X3CrNi13-4 (3)

From these images the length and the height, are the following:
- C45: (1) 1338.19 µm and (2) 815.88 µm;
- 41Cr4: (1) 1518.28 µm and (2) 1208.57 µm;
- X3CrNi13-4 (1): (1) 1485.92 µm and (2) 1016.03 µm;
- X3CrNi13-4 (2): (1) 1572.66 µm and (2) 1083.69 µm;
- X3CrNi13-4 (3): (1) 1439.23 µm and (2) 1164.73 µm.
From these measured values one can observe that the counterpart of C45 sample was the smallest values, which mean that the eroded area was less compared to the other areas of the samples. From the images in Figure 2, the abrasive wear it is observed for the all samples. Besides that, in the case of counterpart for C45 sample, also galling or the pull-out phenomenon is occurred and in the case of the X3CrNi13-4, the abrasive wear is combined with the adhesion wear.

**Figure 3.** Samples wear track profiles (magnification 100 X – 200 µm) for a) C45, b) 41Cr4, c) X3CrNi13-4 (1), d) X3CrNi13-4 (2) and e) X3CrNi13-4 (3)

**Figure 4.** 3D images of samples wear track profiles (height magnification – 200%) for a) C45, b) 41Cr4, c) X3CrNi13-4 (1), d) X3CrNi13-4 (2) and e) X3CrNi13-4 (3)
Also, from Figure 3 can observe the abrasive wear (in the case of the C45 sample and 41Cr4 sample) respectively the abrasive wear and adhesion wear (in the case of X3CrNi13-4 samples). The C45 and 41Cr4 steels have the smallest wear track profiles compared to those of the X3CrNi13-4 stainless steel (Figure 3 and Figure 4).

The 3D images processing with MultiFileAnalyzer (which, like other software presents some advantages [58-61]) show interesting shapes of the wear profiles, especially regarding the wear depth illustrated with blue color. To know exactly which steel has the lowest wear rate values, through MultiFileAnalyzer, in Figure 5 these measurements will be shown by mean of wear track depth and wear track width, and through Table 4 and Figure 6, the wear rate values will be also presented.

**Figure 5.** Depth and width wear track profiles with values for a) C45, b) 41Cr4, c) X3CrNi13-4 (1), d) X3CrNi13-4 (2) and e) X3CrNi13-4 (3)

**Table 4.** Wear rate values

| Sample                | Wear track depth, $h$ (µm) | Wear track width, $s$ (µm) | Cross section area, $A$ (µm$^2$) | Volume loss, $V$ (mm$^3$) | Wear rate, $K$ (mm$^3$N$^{-1}$m$^{-1}$) |
|-----------------------|---------------------------|---------------------------|----------------------------------|---------------------------|-----------------------------------------|
| C45                   | 44.338                    | 1157.318                  | 34246.43                         | 0.8715                    | 1.74·10$^{-4}$                         |
| 41Cr4                 | 47.532                    | 1146.970                  | 36392                            | 0.9284                    | 1.86·10$^{-4}$                         |
| X3CrNi13-4 (1)        | 52.619                    | 1397.131                  | 49062.56                         | 1.2516                    | 2.50·10$^{-4}$                         |
| X3CrNi13-4 (2)        | 53.201                    | 1357.273                  | 48194.32                         | 1.2294                    | 2.46·10$^{-4}$                         |
| X3CrNi13-4 (3)        | 47.440                    | 1344.631                  | 42565.90                         | 1.0858                    | 2.17·10$^{-4}$                         |

**Figure 6.** Comparison between the wear rates
It can be seen that the lowest wear rate value is attributed to the C45 carbon steel followed by 41Cr4 alloyed steel. The same is regarding the worn material volume.

In this case of the three X3CrNi13-4 samples (with highest wear rate values), these have the lowest sliding wear resistance compared with the other two samples. The X3CrNi13-4 martensitic stainless steel samples wear resistance was the following X3CrNi13-4 (3) by 350 rpm, X3CrNi13-4 (2) by 400 rpm and X3CrNi13-4 (1) by 450 rpm. From these assessments, it can be seen that a higher sliding speed can produce a more severe material wear.

According with [62], the authors also tested these materials regarding their cavitation erosion resistance through the stationary specimen method, the material mass losses were as following: C45 - 5.39 mg, 41Cr4 - 2.42 mg, X3CrNi13-4 (1) - 2.22 mg, X3CrNi13-4 (2) - 2.67 mg and respectively X3CrNi13-4 (3) - 4.47 mg. This confirms that an alloy which has a good cavitation erosion resistance due can have a poor sliding wear resistance [63].

Furthermore, according to [64] and [65], with an increasing of the material hardness especially after heat treatment, cavitation erosion resistance can also increase. This is true also from our side, regarding the hardness of these materials from some preview research of the authors, where it can be found that steels like 41Cr4 alloyed steel (which was heat treated) has the highest hardness (around 400 HV) compared to other four samples of this research. We mentioned that because even if in this research, the 41Cr4 steel has a good sliding wear resistance (very close to that of the C45 steel), but the abrasive wear caused to the 100Cr6 counterpart was the highest (as is highlighted in Figure 2 b).

4. Conclusions
The authors pointed out in introduction the presents of sliding wear which occur in many industrial applications due to the dynamic interaction between the mating components and make a connection with other studies in the literature regarding the C45 carbon steels, 41Cr4 alloyed steels and X3CrNi13-4 martensitic stainless steels tribological behaviour and success to make reproducibility with similar researches and their own preview work.

In this way, the main conclusions of the present paper can be summarized as follows:
- the friction coefficient of the tested samples reach values between 0.50 - 0.90 mostly for the C45 steel, which was having the lowest values. So, for the total distance of 500 m, the materials pair (C45 steel and 100Cr6 ball counterpart) showed the best tribological behaviour. After the first 100 m, the steady state was reached and friction coefficient curve was enough stable compared to the other curves, this due to the highest carbon content and formation of the tribofilm.
- the abrasive wear occurred between the tested samples and the 100Cr6 ball counterparts, where in the case of C45 sample sporadic areas of galling were observed and in the case of the X3CrNi13-4 samples, the abrasive wear was combined with the adhesion wear.
- the lowest wear rate value respectively worn material volume was attributed to the C45 carbon steel followed by 41Cr4 alloyed steel and by three X3CrNi13-4 samples especially by X3CrNi13-4 (3), where due to a lowest sliding speed the wear was less.
- the C45 carbon steel showed the good tribological behaviour with the highest dry sliding wear resistance, this confirmed also from the smallest wear track profile. Also the 41Cr4 alloyed steel showed a good sliding wear resistance but as a materials pair, this was produced the highest abrasive wear for 100Cr6 ball as counterpart compared the other tested steels.

References
[1] Nová I and Machuta J 2016 Monitoring of the diffusion processes during carburizing automotive steel parts, Manufacturing Technology 16(1) 225-232
[2] Korka Z I 2017 Reduction of vibration and noise generated by multipoint sources of dynamic contact processes, Romanian Journal of Acoustics and Vibration 14(1) 2
[3] Palásti-Kovács B, Néder Z, Czifra A and Váradi K 2004 Microtopography Changes in Wear Process, Acta Polytech Hung 1(1) 108-119
[4] Gillich G R et al. 2017 Assessing corrosion damage from the natural frequency changes,
Kastawan I M W and Rusmana 2017 Voltage generation of three-phase double sided internal stator axial flux permanent magnet (AFPM) generator, *IOP Conf. Ser.: Mater. Sci. Eng.* **180** 012105

Nedelcu D, Cojocaru V, Ghican A, Peris-Bendu F and Avasiloaie R 2015 Considerations regarding the use of polymers for the rapid prototyping of the hydraulic turbine runners designed for experimental research on the model, *Materiale Plastice* **52**(4) 475-479

Miclosina C O, Balint D I, Campian C V, Frunzaverde D and Ion I 2012 A method to combine hydrodynamics and constructive design in the optimization of the runner blades of Kaplan turbines, *IOP Conference Series: Earth and Environmental Science* **15**(3) 032015

Glăvan D O and Babanatsas T 2018 Tool machinery vibrations frames comparison concerning welded or moulded manufacturing structures, *MATEC Web of Conferences* **121** 1-6

*** 2011 Surfaces for longer life and higher energy efficiency, Sulzer Technical Review 3

Korka Z I, Bara A, Clavace B and Filip L 2017 Gear pitting assessment using vibration signal
analysis, *Romanian Journal of Acoustics and Vibration* 14(1) 44-49

[25] Cindea L et al 2016 The influence of thermal field in the electric arc welding of X60 carbon steel components in the CO2 environment, *Appl Therm Eng* 103 1164-1175

[26] Vencl A et al. 2014 Structural, mechanical and tribological characterization of Zn25Al alloys with Si and Sr addition, *Materials and Design* 64 381-392

[27] Rozing G, Alar V and Marušić V 2015 Study of stainless steel resistance in conditions of tribocorrosion wear, *Interdisciplinary Description of Complex Systems* 13(3) 461-471

[28] Afronie E M, Manescu T S and Ianici S KOD 2012 *Calculus of metalic and steel-concrete mixed structures at fire actions*, 7th International Symposium on Machine and Industrial Design in Mechanical Engineering (KOD 2012) Hungary, May 24-26, pp 515-518

[29] Păduraru L et al. 2018 Investigations on dry sliding wear and corrosion resistance of thermal sprayed molybdenum coatings, *IOP Conf. Ser.: Mater. Sci. Eng.* 416 012027

[30] Glăvan D O, Babanatsas T, Babanatis Merce R M and Glăvan A 2018 Comparative study of tool machinery sliding systems; comparison between plane and cylindrical basic shapes, *IOP Conf. Ser.: Mater. Sci. Eng.* 294 012068

[31] Montesano L, Pola A, Gelfi M and La Vecchia G M 2015 Wear Behavior of Zn-15Al-1Cu-Mg Alloy after Aging, *Procedia Engineering* 109 228-233

[32] Hu J 2016 Development of a Composite Technique for Preconditioning of 41Cr4 Steel Used as Gear Material: Examination of Its Microstructural Characteristics and Properties, *Science and Technology of Nuclear Installations* 2016 1-6

[33] Zurowski W 2012 Structural factors contributing to increased wear resistance of steel friction couples, *Maintenance and Reliability* 14(1) 19-23

[34] Pola A, Gelfi M and La Vecchia G M 2016 Comprehensive numerical simulation of filling and solidification of steel ingots, *Materials* 9(9) 1-13

[35] Suwapanpinj P, Massaro P, Pola A and Sricharoenchai P 2016 *Simulation of precipitation in V-containing hsla steel for the strengthening enhancement*, Proceedings of the 7th European Congress on Computational Methods in Applied Sciences and Engineering, pp 7757-7764

[36] Utu D, Marginean G, Pogan C, Brandl W and Serban V A 2007 Improvement of the wear resistance of titanium alloyed with boron nitride by electron beam irradiation, *Surface and Coatings Technology* 201(14) 6387-6391

[37] Kumar N and Kumar P 2016 Influence of machining parameters on surface roughness and dry friction, *Engineering Solid Mechanics* 4 109-116

[38] Ivan A, Ivan M and Both I 2010 Comparison of FEA and experimental results for a steel frame connection, *WSEAS Transactions on Applied and Theoretical Mechanics* 5(3) 187-96

[39] Both I Wald F and Zaharia R 2016 Benchmark for numerical analysis of steel and composite floors exposed to fire using a general purpose FEM code, *Journal of Applied Engineering Science* 14(2) 275-284

[40] Rigou I V, Mărginean G, Frunzăverde D and Câmpian C V 2012 Silver based composite coatings with improved sliding wear behaviour, *Wear* 290-291 61-65

[41] Marušić V et al. 2018 The possibility of extending work time of tribocouple welding improved stainless steel with improved carbon steel, *MATEC Web of Conferences* 184 01014

[42] Nedeloni M D, Birtărescu E, Nedeloni L, Ene T, Băra A and Clavac B 2018 Cavitation erosion and dry sliding wear research on X5CrNi18-10 austenitic stainless steel, *IOP Conf. Ser.: Mater. Sci. Eng.* 416 012028

[43] Birtărescu E et al. 2018 Some laboratory tests regarding the X20Cr13 martensitic stainless steel behaviour, *IOP Conf. Ser.: Mater. Sci. Eng.* 416 012025

[44] Cojocaru V et al. 2010 *Laboratory tests concerning the influence of surface hardening on the cavitation erosion resistance*, 3rd WSEAS International Conference on Engineering Mechanics, Structures, Engineering Geology, pp 210-213

[45] Nogoud Y A, Abudarag S, Mansor S and Jonker A 2018 Dynamic Analysis and Simulation of a Horizontal Slider Crank Mechanism using Spreadsheets, *Journal of Engineering and
Computer Science 19(1) 13-17

[46] Haris N A et al. 2016 Abrasion and erosion wear properties of surface deformed stainless steel, Journal of Engineering and Applied Sciences 11(12) 7717-7720

[47] Chirila C B, Crescenzo P, Lahire P, Pescaru D and Țundrea E 2004 Factoring Mechanism of Reverse Inheritance, Periodica Polytechnica 49(63) 1-6

[48] Nedelcu D, Cojocaru V, Nedeloni M, Peris-Bendu F and Ghican A 2015 Failure analysis of a Ti-6Al-4V ultrasonic horn used in cavitation erosion tests, Mechanika 4 272-276

[49] Rozing G, Alar V, Marușić V and Samardžić I 2016 Tribocorrosion wear of austenitic and martensitic steels, Metalurgija 55(3) 441-444

[50] Milinović A, Marușić V and Samardžić I 2016 Research into boride layers growth kinetics on C45 carbon steel, Metalurgija 55(4) 671-674

[51] Nedelcu D, Nedeloni M D and Lupinca C I 2014 Cavitation erosion research on the X3CrNi13-4 stainless steel, Materials Science Forum 329 184-192

[52] Li Y, He Y, Xiu J, Wang W, Zhu Y and Hu B 2017 Wear and corrosion properties of AISI 420 martensitic stainless steel treated by active screen plasma nitriding, Surface & Coatings Technology 329 184-192

[53] Nedeloni L, Korka Z I, Pascal D T, Kazamer N and Nedeloni M D 2018 Comparative Study on Dry Sliding Wear Resistance of Carbon Steel, Alloyed Steel and Cast Iron, IOP Conf. Ser.: Mater. Sci. Eng. 416 012026

[54] Krol S, Zalis Z and Hepner M 2005 Comparison of the friction and wear properties of titanium and oxidised titanium in dry sliding against sintered high speed steel HS18-0-1 and against C45 carbon steel, Journal of Materials Processing Technology 164-165 868–875

[55] Marușić V, Nedić B and Stoić A 2009 Application of Tribometer Measurements for Evaluation of Machinability, Metalurgija 51(1) 1-6

[56] *** 2000 Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus ASTM G99

[57] Cozza R C 2013 A study on friction coefficient and wear coefficient of coated systems submitted to micro-scale abrasion tests, Surf Coat Tech 215 224-233

[58] Lahire P, Parigot D, Courbis C, Crescenzo P and Țundrea E 2004 An attempt to set the framework of Model-Oriented Programming, Periodica Polytechnica 49(63) 1-6

[59] Hatiegan C et al. 2015 Finite element analysis of thin plates clamped on the rim of different geometric forms. Part I: Simulating the vibration mode shapes and natural frequencies, Romanian Journal of Acoustics and Vibration 12(1) 69-74

[60] Nedelcu D et al. 2011 The aerodynamic force calculus for a plate immersed in a uniform air stream using Solidworks Flow Simulation module, Proceedings of the 4th WSEAS International Conference, pp 98-103

[61] Nedelcu D et al. 2011 The hydrodynamic characteristics calculus for isolated profile Go428 using Solidworks Flow Simulation module, Proceedings of the 4th WSEAS International Conference, pp 92-97

[62] Hamat C O, Nedeloni M D, Hatiegan C, Ciubotariu R C and Pădureanu I 2015 Cavitation erosion research on C45 carbon steel. Part I: multiple tests of 180 minutes, Annals of „Constantin Brâncuși” University of Târgu Jiu 3 127-132

[63] Gottardi G, Tocci M, Montesano L and Pola A 2018 Cavitation erosion behaviour of an innovative aluminium alloy for Hybrid Aluminium Forging, Wear 394-395 1-10

[64] Petrogalli C et al. 2015 Improvement of Fatigue Resistance of a Tool Steel by Surface Treatments, Procedia Engineering 109 154-161

[65] Pola A, Montesano L, Gelfi M and La Vecchia G M 2016 Comparison of the sliding wear of a novel Zn alloy with that of two commercial Zn alloys against bearing steel and leaded brass, Wear 368-369 445-452