Aspects concerning the cavitation erosion and dry sliding wear behaviour of the YSn83 antifriction alloy and EN-GJS-400-15 spheroidal cast iron

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Abstract. In this paper, the cavitation erosion respectively the dry sliding wear behaviour of the YSn83 antifriction alloy and EN-GJS-400-15 spheroidal cast iron was studied. As cavitation erosion aspects, the authors show some preview results of the YSn83 antifriction alloy behaviour and continue to study and to compare also the cavitation erosion behaviour of the EN-GJS-400-15 spheroidal cast iron. In this regard, the cavitation erosion tests were made using a cavitation stand and the experimental results were presented through mass loss and cavitation erosion rate vs time curves. As dry sliding wear aspects, the tests for the two investigated materials were done with a tribometer through the pin-on-disk method where the authors varied the parameters especially the linear speed and the distance. The obtained results were presented as coefficient of friction evolutions and as wear rates. From all the tests, compared with the YSn83 antifriction alloy, the EN-GJS-400-15 spheroidal cast iron showed a superior cavitation erosion and dry sliding wear behaviour.

1. Introduction

Cavitation erosion and sliding wear are present in various industrial applications such as in the energy, shipping, machine building or automotive industry [1-6]. The cavitation erosion occurs due to the cavitation phenomenon, where the wear mechanism is through erosion and the sliding wear occurs due to the dynamic interaction of the mating components where the abrasive wear is more common [7-13].

Depends on the resistance of the used materials, the operating conditions and the environment, the wear can be more or less [14-19].

The YSn83 antifriction alloy (studied in this paper) is a nonferrous alloy. Such as alloys can be used for ingots, revolution parts (like bearings) or for coatings. Also, the YSn83 antifriction alloy (with a good shock resistance) can be used for sliding bearings manufacturing [20].

Studies regarding these nonferrous alloys and anti-friction materials were made especially concerning their casting and solidification respectively their use in the military technique and aeronautical constructions [21-23].
The other studied material in the present paper (EN-GJS-400-15 spheroidal cast iron) is part of the gray cast iron category and can be used for impact and shock-resistant parts, housings, valve bodies, pipe, cylinders or gear boxes [3], [13], [17].

Due to the good mechanical properties of the cast irons, many studies regarding especially the spheroidal cast irons wear resistance have been achieved [4], [11] and [24-28].

Also, the cavitation erosion respectively dry sliding wear process regarding the resistance / behaviour of some materials (where their mechanical properties were improved through surface and ultrasound treatments or even by nitrogen ion implanted) and coatings like Stellite 6, self-fluxing remelted coatings or through HVOF spraying have been investigated [29-45].

In this regard, the present paper is highlights the cavitation erosion and dry sliding wear behaviour of the YSn83 antifriction alloy respectively EN-GJS-400-15 spheroidal cast iron and try to make reproducibility (regarding similar results and used apparatus) with their own preview work [46-48] and similar studies mentioned above.

To compare the two investigated materials, the experimental results will be presented through micrographs respectively mass loss and cavitation erosion rate vs time curves (concerning the cavitation erosion behaviour) and as friction coefficient evolution and as wear rates (concerning the dry sliding wear behaviour).

2. Materials and methods
The materials used in this research are the YSn83 antifriction alloy and the EN-GJS-400-15 spheroidal cast iron, where the chemical composition of them is reported in Table 1 and Table 2.

Table 1. YSn83 antifriction alloy chemical composition (wt.%)

| Cu | Sb | Pb | Fe | Sn |
|----|----|----|----|----|
| 3.53 | 10.9 | 0.55 | 0.06 | 84.96 |

Table 2. EN-GJS-400-15 spheroidal cast iron chemical composition (wt.%)

| C | Si | Mn | P | Cu | Cr | Mg | Ni | S | Fe |
|---|----|----|---|----|----|----|----|---|----|
| 3.5 | 2.06 | 0.22 | 0.050 | 0.04 | 0.04 | 0.038 | 0.03 | 0.015 | 93.99 |

From these materials, two cubic samples with the edges of 16 mm were made and tested on the cavitation stand respectively on tribometer.

The cavitation stand is composed of: ultrasonic generator, electro-acoustic piezo converter, acoustic transformer, ultrasonic horn and respectively of the water container, the sample support and the tested sample.

The stationary specimen method was used and the tests were realized according to G32-10 standard [49] with the following main parameters from Table 3.

Table 3. Parameters for cavitation stand / cavitation erosion tests

| Frequency (kHz) | Amplitude (µm) | Water temperature (°C) | Horn and sample distance (mm) |
|-----------------|----------------|------------------------|-------------------------------|
| 20 ±0.5         | 50             | 25 ±2                  | 0.6                           |

For these tests the total cumulated time was 150 minutes, divided into one period of 5 and 10 minutes respectively in nine periods of 15 minutes. After each period the mass loss of the samples was weighed with the help of a digital balance.
The tribometer arrangement was a pin holder with a 100Cr6 steel ball (6 mm in diameter) respectively the tested samples. For these sliding wear tests the authors varied the samples radius, linear speed, working speed respectively the distance.

The pin-on-disk method (POD) was used according to G99 standard [50] with the following main dry sliding parameters from Table 4 and Table 5.

**Table 4.** YSn83 antifriction alloy dry sliding wear parameters

| Faces    | Load (N) | Radius (mm) | Linear speed (mm s⁻¹) | Working speed (rpm) | Distance (m) | Distance (laps) |
|----------|----------|-------------|------------------------|---------------------|--------------|-----------------|
| Face 2 (1) | 5        | 1.5         | 46.2                   | 300                 | 10           | 1090            |
| Face 2 (2) | 5        | 3           | 85.7                   | 275                 | 10           | 536             |
| Face 2 (3) | 5        | 4.5         | 117.5                  | 250                 | 10           | 355             |
| Face 2 (4) | 5        | 6           | 141.5                  | 225                 | 10           | 267             |
| Face 1 (1) | 7        | 1.5         | 30.8                   | 200                 | 7.5          | 815             |
| Face 1 (2) | 7        | 3           | 61.8                   | 200                 | 10           | 541             |
| Face 1 (3) | 7        | 4.5         | 93.6                   | 200                 | 12.5         | 446             |
| Face 1 (4) | 7        | 6           | 123.7                  | 200                 | 15           | 406             |

**Table 5.** EN-GJS-400-15 spheroidal cast iron dry sliding wear parameters

| Faces    | Load (N) | Radius (mm) | Linear speed (mm s⁻¹) | Working speed (rpm) | Distance (m) | Distance (laps) |
|----------|----------|-------------|------------------------|---------------------|--------------|-----------------|
| Face 1 (1) | 7        | 1.5         | 85.1                   | 550                 | 100          | 10800           |
| Face 1 (2) | 7        | 3           | 163.9                  | 525                 | 100          | 5340            |
| Face 1 (3) | 7        | 4.5         | 234.4                  | 500                 | 100          | 3560            |
| Face 1 (4) | 7        | 6           | 297.9                  | 475                 | 100          | 2660            |
| Face 2 (1) | 10       | 1.5         | 58.7                   | 400                 | 75           | 8080            |
| Face 2 (2) | 10       | 3           | 121.1                  | 400                 | 100          | 5510            |
| Face 2 (3) | 10       | 4.5         | 186.7                  | 400                 | 125          | 4470            |
| Face 2 (4) | 10       | 6           | 249.5                  | 400                 | 150          | 4020            |

By using the tribometer software, the friction coefficient was monitored and the wear rate was calculated with equation 1 [50]:

$$K = \frac{2\pi \cdot h (3h^2 + 4s^2)}{6 \cdot L \cdot d \cdot s}$$  \hspace{1cm} (1)

where: $K$ is the wear rate; $h$ – the wear track depth; $s$ – the wear track width; $L$ – the load and $d$ is the distance (in meters).

Based on some preview tests, for this research the testing time for YSn83 antifriction alloy was only between 1 - 4 minutes respectively 5 - 20 minutes for the EN-GJS-400-15 spheroidal cast iron.

For the two types of tests (cavitation erosion and dry sliding wear), the samples were polished with abrasive paper in order to have a roughness around 0.8 μm and were cleaned with acetone.
3. Results and discussions

3.1. Cavitation erosion behaviour

Regarding the cavitation erosion YSn83 antifriction alloy behaviour, based on the reference [20], the authors present some preview results and compare them with experimental results regarding the cavitation erosion behaviour of the EN-GJS-400-15 spheroidal cast iron.

Comparatively, the main results are shown in Table 6 and in detail in Table 7 for EN-GJS-400-15 spheroidal cast iron, where the mass loss was much less than for YSn83 antifriction alloy.

Table 6. Comparison between the cavitation erosion results

| Samples          | Sample mass (mg) Before | Max. mass loss (mg) | Max. cavitation rate (mg·h⁻¹) |
|------------------|------------------------|---------------------|------------------------------|
|                  | m (mg)                 | Δm (mg)             | Cumulative m (mg)             |
| YSn83            | 31230.37               | 30592.87            | 127.21                       |
| EN-GJS-400-15    | 28314.86               | 28301.53            | 1.4                          |

Table 7. Cavitation erosion results for the EN-GJS-400-15 spheroidal cast iron

| Cumulated time | Period (min) | Sample mass | Eroded mass loss | Cavitation rate |
|----------------|--------------|-------------|------------------|-----------------|
| t (min)        | Δt (min)     | m (mg)      | Δm (mg)          | Vec (mg·h⁻¹)    |
| 0              | 0            | 28314.86    | 0                | 0.000           |
| 5              | 5            | 28313.7     | 1.16             | 11.800          |
| 15             | 10           | 28312.44    | 1.26             | 6.328           |
| 30             | 15           | 28311.32    | 1.12             | 4.620           |
| 45             | 15           | 28310.13    | 1.19             | 4.800           |
| 60             | 15           | 28308.92    | 1.21             | 4.560           |
| 75             | 15           | 28307.85    | 1.07             | 4.740           |
| 90             | 15           | 28306.55    | 1.3              | 5.080           |
| 105            | 15           | 28305.31    | 1.24             | 4.740           |
| 120            | 15           | 28304.18    | 1.13             | 4.760           |
| 135            | 15           | 28302.93    | 1.25             | 5.300           |
| 150            | 15           | 28301.53    | 1.4              | 5.920           |

Also, only for the EN-GJS-400-15 spheroidal cast iron sample, the cumulative mass loss and cavitation erosion rate vs time curves are presented in Figure 1 and 2. From these two types of curves, it can observed that the mass loss process is linearly and the cavitation erosion rate cross the characteristic stages (incubation, acceleration, maximum rate and deceleration [49]) for the first 30 minutes and then it is maintain between the range of 4 - 6 mg·h⁻¹.

For a better comparison, in Figure 3 the eroded samples surfaces are presented through images acquired with a digital microscope (Keyence VHX-600).

From this Figure, in the case of YSn83 antifriction alloy, visible caverns (with a depth until 300 µm) can be observed and in the case of EN-GJS-400-15 spheroidal cast iron, pits (with a depth until 100 µm) take place.
From others results of the authors, this cast iron has a better cavitation erosion resistance than some Al alloys [51-53] but a poor once than the C45 carbon steel, some bronzes and stainless steels [54-56].
3.2. YSn83 antifriction alloy dry sliding wear behaviour

For the YSn83 antifriction alloy the main results (coefficient of friction evolutions, wear tracks profiles and the wear rate values) are presented in Figures 5 ÷ 10 and in Table 8.

![Figure 5](image_url). Coefficient of friction evolutions for the YSn83 antifriction alloy at 5N load

![Figure 6](image_url). Coefficient of friction evolutions for the YSn83 antifriction alloy at 7N load
Figure 7. Wear tracks profiles for the YSn83 antifriction alloy at 5N load

Figure 8. Wear tracks profiles for the YSn83 antifriction alloy at 7N load
Figure 9. 3D wear track details for Face 1(4) of the YSn83 antifriction alloy

![3D wear track details for Face 1(4) of the YSn83 antifriction alloy](image)

Figure 10. Comparison between the wear rates for the YSn83 antifriction alloy

![Comparison between the wear rates for the YSn83 antifriction alloy](image)

Table 8. Wear rate values for the YSn83 antifriction alloy

| Faces       | 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$^{-1}$) |
|-------------|---------------------------|---------------------------|----------------------------------|--------------------------|----------------------------------------|
| Face 2 (1)  | 11.887                    | 626.825                   | 4968.72                          | 0.0468                   | 9.37·10$^{-4}$                         |
| Face 2 (2)  | 19.831                    | 872.150                   | 11534.88                         | 0.2174                   | 4.35·10$^{-3}$                         |
| Face 2 (3)  | 16.297                    | 792.796                   | 8616.19                          | 0.2436                   | 4.87·10$^{-3}$                         |
| Face 2 (4)  | 12.780                    | 590.187                   | 5030.16                          | 0.1896                   | 3.79·10$^{-3}$                         |
| Face 1 (1)  | 16.328                    | 655.473                   | 7138.36                          | 0.0673                   | 1.28·10$^{-3}$                         |
| Face 1 (2)  | 16.632                    | 731.329                   | 8112.12                          | 0.1529                   | 2.18·10$^{-3}$                         |
| Face 1 (3)  | 11.734                    | 792.858                   | 6203.28                          | 0.1754                   | 2·10$^{-3}$                            |
| Face 1 (4)  | 19.149                    | 892.882                   | 11402.46                         | 0.4299                   | 4.09·10$^{-3}$                         |

It can be seen that almost all the coefficient of friction evolutions has reached the steady state stage, except one (Figure 5 d). In all these curves, the coefficient of friction mean values was between 0.179 and 0.553. The Figures 7 and 8 show that only for small distances (between 7.5 and 15 m), the YSn83 antifriction alloy presented a severe abrasion wear. Regarding the wear rates values, these tend to increase with increasing the radius and linear speed as it can be seen from Figure 10 and from the volume loss values. At small radius and linear speeds values, the wear rate is the lowest.
3.3. EN-GJS-400-15 spheroidal cast iron dry sliding wear behaviour
For the EN-GJS-400-15 cast iron the main results (coefficient of friction evolutions, wear tracks profiles and the wear rate values) are presented in Figures 11 ÷ 16 and in Table 9.

![Figure 11. Coefficient of friction evolutions for the EN-GJS-400-15 cast iron at a load of 7N](image1)

![Figure 12. Coefficient of friction evolutions for the EN-GJS-400-15 cast iron at a load of 10N](image2)
Figure 13. Wear tracks profiles for the EN-GJS-400-15 cast iron at a load of 7N

Figure 14. Wear tracks profiles for the EN-GJS-400-15 cast iron at a load of 10N
It can be seen that all the coefficient of friction evolutions are quite similar with small values (between 0.085 and 0.130).

Figures 13 and 14 show that the EN-GJS-400-15 spheroidal cast iron presented a slightly abrasion wear. The wear rates values increase with increasing the radius and linear speed as it can be seen from Figure 16 and especially from the volume loss values (Table 9). The lowest wear rate took places at a working speed of 400 rpm for the small radius, linear speed respectively distance.

### Table 9. Wear rate values for the EN-GJS-400-15 cast iron

| Faces     | Wear track depth, $h$ (µm) | Wear track width, $s$ (µm) | Cross section area, $A$ (µm²) | Volume loss, $V$ (mm³) | Wear rate, $K$ (mm³N⁻¹m⁻¹) |
|-----------|---------------------------|-----------------------------|-------------------------------|------------------------|-----------------------------|
| Face 1 (1)| 2.001                     | 169.824                     | 226.61                        | 0.0021                 | 3.05·10⁻⁶                   |
| Face 1 (2)| 1.844                     | 192.839                     | 237.08                        | 0.0045                 | 6.38·10⁻⁶                   |
| Face 1 (3)| 1.977                     | 178.636                     | 235.42                        | 0.0067                 | 9.51·10⁻⁶                   |
| Face 1 (4)| 2.488                     | 176.057                     | 292.03                        | 0.0110                 | 1.57·10⁻⁵                   |
| Face 2 (1)| 1.261                     | 182.048                     | 153.05                        | 0.0014                 | 1.92·10⁻⁶                   |
| Face 2 (2)| 1.777                     | 203.103                     | 240.58                        | 0.0045                 | 4.53·10⁻⁶                   |
| Face 2 (3)| 1.477                     | 191.565                     | 188.64                        | 0.0053                 | 4.27·10⁻⁶                   |
| Face 2 (4)| 1.724                     | 177.810                     | 204.38                        | 0.0077                 | 5.14·10⁻⁶                   |
4. Conclusions
The paper presented a comparison between the YSn83 antifriction alloy and EN-GJS-400-15 spheroidal cast iron regarding their cavitation erosion respectively dry sliding wear behavior.

After the cavitation erosion tests, YSn83 antifriction alloy has lost 637.5 mg material loss and show visible caverns until 300 µm depth. The EN-GJS-400-15 spheroidal cast iron lost only 13.33 mg material loss and show small pits until 100 µm.

For the dry sliding wear tests, in the case of the EN-GJS-400-15 spheroidal cast iron, the distance was 10 times more than that in the case of the YSn83 antifriction alloy. After these tests, for the two tested materials the coefficient of friction was obtained respectively the wear rate was calculated. The YSn83 antifriction alloy show a severe abrasion wear and the EN-GJS-400-15 spheroidal cast iron show slightly abrasion wear. Regarding the tribometer parameters, by increasing the linear speed, the materials will lose more volume loss of material and the wear rate values will increase. At small linear speeds values, the wear rate is lowest.

From all the tests, the EN-GJS-400-15 spheroidal cast iron showed a superior cavitation erosion and dry sliding wear behaviour.

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