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Short communication

On some tribological effects of graphite nodules in wear mechanism of SG cast iron: Finite element and experimental analysis

M. Ben Tkaya[a,*], S. Mezlini[c], M. El Mansori[a], H. Zahouani[b]

[a] Laboratoire de Mécanique et Procédés de Fabrication (LMPF), Arts et Métiers ParisTech, Rue Saint Dominique BP 508, 51006 Châlons-en-Champagne, France
[b] Laboratoire de Tribologie et Dynamique des Systèmes, UMR 5513 CNRS – ECL – ENISE, Ecole Centrale de Lyon, BP 163, 69131 Ecully cedex, France
[c] Laboratoire de Génie Mécanique, Ecole Nationale d'Ingenieurs de Monastir 5000, Tunisia

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ABSTRACT

Thanks to its mechanical and tribological performances compared to the other types of steel, cast iron has been more and more used. Ductile iron is used for several structural applications, particularly when both rigidity and good machinability are required. The second largest area of application of ductile iron is the automobile industry thanks to its lower density, good wear resistance and its low friction coefficient. In this work an experimental wear test emphasizes the role of graphite in the tribological behaviour of a nodular cast iron. Correlation between tribological parameters and wear mechanisms has been investigated. Particularly, the effect of normal load and attack angle of conical indenter on the wear mechanisms has been checked out. The numerical model has also been investigated in order to better understand the tribological graphitic behaviour. It also highlights the correlation between tribological parameters and wear mechanisms.

1. Introduction

Nodular cast iron is a heterogeneous material. The macroscopic properties of this material have been often measured using a traction test [1]. However, the microscopic study showed that damage is produced by the plastic cavitations and the instability of the ductile matrix surrounding the graphitic spheroids that act like a wide cavity. Severe damage can be produced by the growth of the cavitations that surround the inclusions in the ferretic phase [2]. Fig. 1 represents the meso-scale of the nodular cast iron. It shows that the material contains three phases: ferrite (white), pearlite (grey) and graphitic spheroid (black). In this case the matrix can be considered as formed by two constituents: ferrite and pearlite.

Furthermore, tribological behaviour of nodular cast iron depends, on one hand, on the different individual constituent properties and their interactions and on the other hand on the tribological parameter system [3–5]. Generally, the micro-mechanical models have been used to understand the local mechanisms which govern the elastic and plastic deformation of a heterogeneous material. It supplies the global response of the heterogeneous material using different properties of every individual constituent and their interactions [6].

Our study consists of an experimental simulation of a rigid cone sliding against nodular cast iron sheet. Wear mechanisms and friction coefficient have been analysed. To achieve this objective, a scratch test was used to study nodular cast iron. A cone with different attack angles on plane contact configuration was used. Wear mechanisms have been analysed and the correlation between these mechanisms, friction coefficient and tribological parameters have been discussed. A numerical simulation of scratch test has also been investigated. The effect of normal load as well as conical attack angle has been analysed. Numerical simulation allows to better understanding the evolution of wear mechanisms with tribological parameters. The influence of tribological parameters, particularly, attack angle and normal force on tribological behaviour has also been studied.

2. Experimentation

2.1. Experimental devices

To simulate elementary abrasive wear of the nodular cast iron, a scratch test has been used (Fig. 2). This test, which has already been described [7], produces scratches using a rigid indenter. The sample surface is positioned in parallel to the indenter motion, by a specific automatically controlled process. The unit is controlled by a computer, which also controls the various test parameters. Concerning the scratch test configuration, a contact between a diamond cone and nodular cast iron is considered. After applying a normal force on

* Corresponding author. Tel.: +33 677495894.
E-mail address: tekaya_m@yahoo.fr (M.B. Tkaya).

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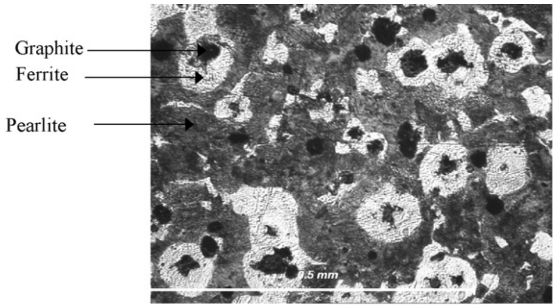

Fig. 1. Meso scale structure of a nodular cast iron.

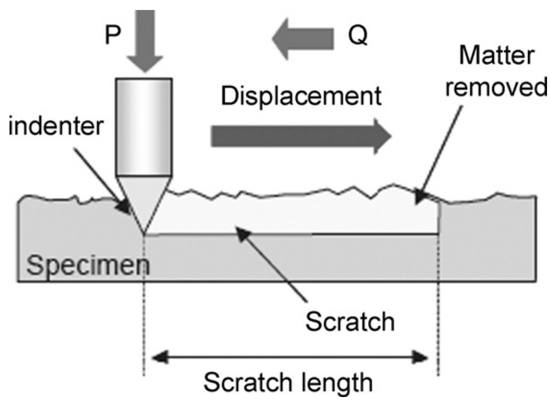

Fig. 2. Scratch test configuration.

the indenter, a sliding movement is carried out. The normal force (P) and the tangential force (Q) can be simultaneously measured using a piezo-electric transducer located underneath the sample. A conical indenter with different attack angles (10°, 30° and 45°) was used in this study.

The scratch length and the sliding velocity were fixed at 5 mm and 0.1 mm/s, respectively. The normal load P has been varied from 2N to 25N (Fig. 2). For each test, wear volume was measured using a 3D profilometer and wear mechanisms were investigated by SEM observations.

The material properties of each nodular cast iron constituent are measured using an instrumented micro-indentation test (Table 1).

2.2. Results

Fig. 3 illustrates the scratch morphology of nodular cast iron for different conical attack angles (10° and 45°) and relative to a normal load of 5N. For a conical attack angle of 10° (Fig. 3a), a part of material is pushed to the side of the scratches and formed a wedge while the rest is pushed in front of the indenter. In this case all the materials are pushed to the sides or to the front of the indenter without loss of material. However, when the conical attack angle increases, "chips" are observed. So for normal load of 5N, and at 45° attack angle, we have a transition of wear mechanisms from ploughing to cutting. Fig. 3b shows cutting mechanisms with the formation of chips in front and by the sides of the indenter.

When analysing wear mechanisms according to different attack angles and for a normal load of 5N, three regions can be distinguished. When the attack angle is below 30°, a ploughing mechanism occurs whereas for an attack angle greater than 45°, a cutting mechanism dominates. For intermediate attack angles a transition from ploughing to cutting wear mechanism has been observed. A similar result was obtained in a previous study [8].

The previous study [8] showed that, for the aluminium alloys, the wear mechanisms are slightly] dependent on the normal load and the transition of wear mechanisms always occurred at the same critical attack angle. In this study, the variation of normal load shows that the tribological behaviour of nodular cast iron is different from that observed for the aluminium alloys. In fact, when the normal load is greater than 15N, cutting mechanism occurs for different attack angles (10°, 30° and 45°) and the ploughing region, observed for a low normal load, does no longer exist. Fig. 4 illustrates the scratch morphology of nodular cast iron for a normal load of 15N and for different attack angle 10°, 30° and 45°. It was observed that increasing normal load causes the apparition of cutting wear mechanisms for low attack angles (<30°). This phenomenon is probably governed by the presence of graphitic phase in the nodular cast iron and it will be discussed later. So, the presence of graphite particles renders this material to have high rates of metal removal than other materials such as steel and aluminium.

The evolution of the apparent friction coefficient ($\mu = Q/P$) was also investigated according to the applied load and the attack angle of the indenter (Fig. 5). It shows that the friction coefficient increases as the attack angle of the conical indenter increases. In fact, increasing the attack angle generates the transition of the wear mechanism from ploughing to cutting. This transition is accompanied by the severe plastic deformation necessary to generate a chip and damage the nodular cast iron.

Table 1
Mechanical properties of tested materials.

Different constituents of nodular cast iron	Young modulus, E (GPa)	Poisson ratio, ν	yield stress, σ_0 (MPa)
Ferrite	209	0.3	427
Pearlite	209	0.3	552
Graphite	17	0.4	50

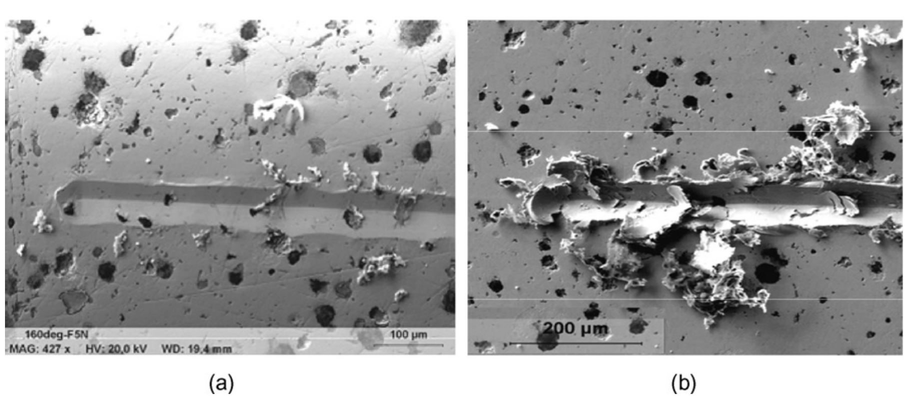

Fig. 3. SEM observations of nodular cast iron scratches for normal load 5N and for different conical attack angle: (a) 10° and (b) 45°.