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Effect of manganese, silicon and chromium additions on microstructure and wear characteristics of grey cast iron for sugar industries applications

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ABSTRACT

Mill roller shells are amongst the most important manufacturing-line elements in the sugar production process. They are carefully designed according to many surface criteria amongst which wear resistance is the most important. To increase the life of the mill roller shells, the resistance of the surface to failure by abrasion should be increased. In this investigation, a series of sixty-six cast iron samples with varied contents of chromium, manganese and silicon were prepared. The microstructure and the mechanical properties were studied. Hence, the wear of all the specimens was evaluated using the pin-on-disc test, with a high-speed steel disc. The accumulated weight loss was measured and the wear rates were determined at constant normal test load of 20 N and constant pin velocity of 1.28 m/s during the pin-on-disc test. The accumulated weight loss was measured as a function of the number of revolutions. From test results, it was found that the wear rate, for all conditions under investigation, decreases with the increase of manganese and chromium additions at constant silicon additions. The wear rate obtained for the samples containing 3% manganese and 2.02% silicon was equal to 1.2267 mg/s, and the minimum wear rate was obtained for the samples containing 3% manganese, 2.11% silicon, and 2.11% chromium (equal to 0.3400 mg/s). The enhancement in the wear resistance of the chromium alloyed samples was attributed to the increase in the chromium carbides volume fraction.

1. Introduction

Mill roller shells are usually constructed of a shaft of steel [1] onto which a cast iron shell is shrunk [2]. Sugar Mill roller shells are important surface engineered insert elements, which are manufactured in the Foundry of Hawamdia Machinery & Equipment Factories, from grey cast iron. Mill roller breakages are fairly common and invariably costly, not only because of the need to replace them but also due to the downtime that results from their breakage. Moreover, their breakage is usually associated with secondary damage to the bearings and the headstock. The purpose of the mill headstocks is to maintain the working elements (particularly the rolls) in their desired orientation. This orientation needs to be flexible to allow for different roll sizes and setting. The basic mill comprises three mills: the top roll, which needs to be able to "float" upwards during operation, and the feed and discharge rolls that need to be adjustable sideways. The company consumes a large quantity of mill roller shells, approximately (1200) tonne/year and the cost of this production rate is nearly (12) million Egyptian pounds. The Egyptian Sugar Integrated Industries Company adopts a program for annual maintenance for the mill roller shells to prevent failure during the season as failure costs a big pity.

The average lifetime of mill roller shells in Egyptian Sugar & Integrated Industries Company (ESIIC) before the first restoration is approximately one year the main damage occurring to the surface is abrasive wear. For example, the Kawasaki mill roller shell diameter changes by 20 mm each season; from 1120 mm to 1100 mm, 1080 mm and 1060 mm, consecutively, as shown in Fig. 1. Usually, there are three restoration maintenance repairs conducted when the worn surface reaches about (1.8%) of the diameter. The restoration includes machining of the worn surface and regrooving of the new surface. This is associated with a decrease in the diameter resulting in a loss in productivity of the mills. For economic purposes, the restoration is done three times till the diameter is drastically reduced and the mill roller is put out of the service.

There are many reasons for corrosion and wear in mill roller shells. such as rust of metal mill rollers (as a result of the presence of acidic juice); friction between the top scraper-trash plate-cane- sucker and mill rollers; and on top of all the high speed of the moving rolls [3], where the wear in the middle of the mill rollers is greater than their ends. Usually, the wear is 1.8% (or in other words 20 mm) annually,

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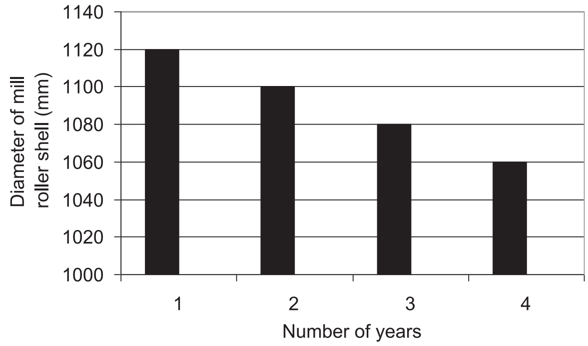

Fig. 1. Annual wear of mill roller shell.

and the tool life for mill rollers is about (3–5) years.

The favoured specification for mill roller shells used to be "open-grained cast iron", since this produced a rough finish to aid feeding. However, with higher loads and stresses and the development of roll surface roughening techniques such as carbon-arcing and subsequently hard welding a close-grained, the higher tensile material is now preferred. The material should be free from blowholes and cracks. Wear rate increases with the decrease of angle grooves and the optimum angle for mill roller is 45°: 55° [3]. Three type of grooving is generally used on mill rollers [3,4].

- Fine grooves 5–20 mm pitch.
- Medium grooves 20–50 mm pitch.
- Coarse grooves above 50 mm pitch.

The fine grooves are best for extraction and the coarse ones are best for crushing. Some engineers adopt identical grooves on all mill rollers, from the extraction point of view, while others favour differential grooving as by these juice handling capacity increases. The wear and tear, however, in the case of differential grooving is greater than in the case of identical grooving. The angle of grooving is also important. In recent practices, wider angles of (55–60°) are generally employed on the top rollers and (52–58°) on the bottom rollers.

Wear resistance is considered as the most important parameter for proper selection of the material to be used for the manufacturing of mill roller shells. Hardness, microstructure and chemical composition of mill roller shells play a marked role in wear resistance [5]. Although hardness and relative wear are linearly proportional for most of the commercial pure metals, the same simple relation does not hold for a range of mill roller shells where it becomes necessary to consider chemical composition as well.

Shells have historically been made of low strength cast iron. The desired properties of the final shell material include resistance to wear and polishing, suitable strength and good machineability and weldability. Being of a large section, the shell casting requires careful attention to prevent undue porosity and shrinkage cavities. Once the casting has cooled at the correct rate, it is machined for the retelling of a shaft. Precise machining of the internal through hole is critical to ensure an adequate shrink fit onto the shaft to avoid shell slippage in service [6]. Despite the significance of this issue, there is not much research on this subject. Previous work only studied the surface of grey cast iron rollers arced in traditional ways.

A recent study [7] on eight factories in Jamaica using grey cast iron for their mill roller shells revealed that much more direction and testing of the material specification are required from factories to manufacturers when purchasing mill roller shells. The findings showed that specifications are seldom requested. Later on, researches started to recognise the importance of chemical analysis [8] but research on this subject is still lacking. Good practice, based upon the work carried out by Sare, Constantine, Mason and Thwaite [8] suggested an alloy composition of (3.3–3.5% C, 1.6–2.0% Si, 2.0–3.0% Mn, 0.07–0.10%S, and < 0.07% P), with the overriding constraint that the Carbon Equivalent (CE) level = 3.9–4.2%.

Some studies focused on the hard facing of the grey cast iron rollers using similar welding electrodes [8]. The engineered surfaces were characterised for their abrasion and corrosion wear resistance. The results of the previous studies [8] suggested that the predominant wear mechanism is corrosion associated with porosity and Cr depletion in the weld zone.

The main objective of this study is to bring into focus the significance of the chemical composition of the cast iron used for manufacturing the shells in order to increase juice extraction with minimum wear at the lowest cost. According to Krauss [9], the addition of each 1.00%, silicon reduces the amount of carbon in the eutectic by 0.33%. The most common range for manganese in grey iron is from 0.55% to 0.75%. Increasing the manganese content tends to promote the formation of pearlite while cooling through the critical range. It is necessary to recognise that only that portion of the manganese not combined with sulphur is effective. Virtually, all of the sulphur in grey iron is present as manganese sulphide, and the manganese necessary for this purpose is 1.7 times the sulphur content. Manganese is often raised beyond 1.00%, but in some types of green sand castings, pinholes may be encountered. Chromium is generally present in amounts below 0.10% as a residual element carried over from the charge materials. Chromium is often added to improve hardness and strength of grey iron, and for this purpose, the chromium level is raised to 0.20–0.35%. Beyond this range, it is necessary to add a graphitised to avoid the formation of carbides and hard edges. Chromium improves the elevated temperature properties of grey iron. The aim of this experimental study is to study the effect of adding (2.11% chromium, 3% manganese and 2.02% silicon) to grey cast iron cast shells in order to improve the wear resistance of the surface. The alloy design is based on adding Cr as carbide former with increased Si content to approach the upper limit in grey cast iron to act as a graphitised. Mn is also raised up to 2% to provide plentiful amounts to stabilise the pearlite.

2. Experimental work

2.1. System description

The main objective of milling is to separate the sucrose containing juice from the cane. The prepared cane is pushed through a three-roller mill and squeezed between the top roller and the feed roller. The juice is extracted and collected in a trough and a trash plate guides the bagasse resulting from squeezing to the opening between the top roller and the discharge roller, where it is squeezed once again in the set of the three-roller mill. In a three- roller mill, three rollers are arranged in a triangular pattern for removing sucrose up to 96–97% max. The arrangement of the rollers is shown in Fig. 2.

The three roller mills used for extraction of juice consist of top feed and discharge rollers. Sugar cane is fed into the top and feed rollers, then further pass through the top and discharge rollers along with trash plate. This trash plate has a downside such that 25% of the total hydraulic load is shared by this trash plate in overcoming friction and the remaining 75% only is useful, i.e. 25% of the hydraulic load is shared by feed roller and 50% is shared by the discharge roller, as shown in Fig. 3. The crushing rolls are designed to have a high coefficient of friction and are operated at very low rotational speeds up to 4–7 rpm.

The power needed for crushing the sugarcane is applied on to the top roller, which rotates the feed and discharge rollers, with pinion arrangement attached on one side of the roller. The direction of rotation of top and feed–discharge rollers is opposite. The top roller is the most critical component amongst all, as the drive torque, hydraulic load and crushing load all act on it. The forces acting on the mill roller gives rise to shearing, bending, torsion and compressive stress. The top roller is most highly stressed since it consumes about half of the mill torque. Out of total power, 50% is taken by top roller, 35% is taken by discharge