Available online at www.sciencedirect.com
ScienceDirect
journal homepage: http://www.elsevier.com/locate/acme

Original Research Article

Nitrogen as an alloying element improving material properties of the high carbon cast steel for ball mill liner plates

Józef Gawlik[a], *Jerzy Schmidt*[a,*], *Tomasz Nowak*[b], *Zygmunt Wójcicki*[a], *Andrzej Zagórski*[c]

[a] *Cracow University of Technology, Jana Pawła II 37 Street, Cracow, Poland*
[b] *ABB Corporate Research, Starowislna 13A Street, Cracow, Poland*
[c] *Warsaw University of Technology, Woloska 141 Street, Warsaw, Poland*

ARTICLE INFO

Article history:
Received 16 January 2017
Accepted 15 April 2017
Available online

Keywords:
High carbon chromium cast steel
Casting
Nitrogen
Wear resistance
Heat treatment

ABSTRACT

This paper presents an experimental analysis, which was carried out to evaluate the addition of nitrogen as an element complementing a chemical composition used for such cast parts. It has been demonstrated that nitrogen is very advantageous in the process of austenitizing and quenching, improving the stability and homogeneity of the alloy structure. Plates used as a lining of rotary mills operating in cement plants are castings, which acquire their properties mainly through proper heat treatment. Together with an appropriate microstructure and chemical composition, correct heat treatment allow to improve the wear resistance and significantly reduce the abrasive corrosion. Extensive investigations enabled establishing an optimum nitrogen content in the chemical composition of thick-walled castings used in cement industry. Results of experiments, managed for the steel of ledeburate type containing 0.8–1.2% of carbon, have found that the optimal level of nitrogen is in the amount of 0.07–0.10%. The proposed modification helped to reduce the amount of an expensive chromium, increase the hardness of the material (by about 2 HRC to 4 HRC), and to achieve the uniform microstructure and hardness, which noticeably improved the lifetime of the rotary mills plates.

1. Introduction

While grinding is unavoidable in nearly all mineral processing, it has tremendous impact on the economics of comminution facilities worldwide. The main contributors to the cost structure of mineral processing are a consumption of grinding media in mills and wearing-out of mill elements, especially liner plates [1,2]. The wear out process arises as a consequence of complex interaction between variables related to processing conditions and the characteristics of the media [3]. Due to high efficiency of the industrial mills used in cement industry, there are also high energies and friction forces generated. The objects analyzed in this paper, the thick-walled plates lining

---

* *Corresponding author.*
E-mail address: schmidt@mech.pk.edu.pl (J. Schmidt).

http://dx.doi.org/10.1016/j.acme.2017.04.007
1644-9665/

the inner surfaces of the drums of ball mills used in cement plants, may be affected by the three basic wear mechanisms – impact, abrasion and corrosion, which simultaneously influence mass loss in mill components [4]. The effect of the abrasive mineral on alloy performance in the ball mill has been studied by Gates et al. [5]. Their results showed, that only very hard (above 630 HV) martensitic steels and white cast irons offer large performance benefits when grinding relatively soft or weak abrasives (Mohs hardness less than about 6). The researchers studied the relationship between wear performance and microstructure [6,7], hardness [8,9], or impact toughness. For example, Efremenko and co-workers [10] suggest, that the best wear performance is achieved with martensitic structure in steels containing not less than 13 wt.% Cr, while others [11] recommend that the medium chromium cast iron ball type in the heat-treated condition has the desired microstructure – mechanical property – wear performance combination. Azizi reminds that abrasive corrosion was observed on high carbon chromium steel ball surface, and that the main corrosion mechanism type for steel balls is pitting [12]. This article refers to the steel of ledeburite type, which is mainly used for cutting and shaping tools [13], as well as high pressure moulds. While used as hammers and jaws in crushers, ledeburitic steel offers good resistance against abrasive wear, if proper steel microstructure and its heat treatment are ensured. Properly heat treated material after the effective sorbitization process should have uniform hardness in the range of 46 HRC to 50 HRC [14]. The literature provides comprehensive reference for investigation of the heat treatment process and the microstructure on and mechanical properties of steels and cast iron [15–17]. For example, Tao and co-workers noticed that additional carbides and nitrides precipitations introduce changes in dislocation structure and the formation of sub-grains occurring during the process of tempering [18]. Similarly, Kaputkina [19] and Prokoskina [20] studied the structure and properties formed as a result of martensitic transformations during cooling and subsequent tempering, in metastable carbon- and nitrogen-containing austenitic iron alloys. The presence of carbides and nitrides also makes the dispersion hardening of the austenite and martensite more effective [21,22]. Gavriljuk, who studied crystal structure of austenite and martensite in nitrogen- and carbon-containing iron alloys, explains that carbon assists the covalent character of interatomic bonds, whereas nitrogen increases the concentration of conduction electrons [23,24]. In the ledeburitic steels the total volume fraction of carbides is normally large, and during heating a large amount of carbides dissolve. But non-dissolved carbides are left behind in the austenite matrix, which influence the mechanical properties and improves wear resistance [25,26]. The combined effect of nitrogen and chromium content on the microstructures of cast alloys was investigated by Suyalatu and co-workers [27]. They found that ultimate tensile strength and elongation at break of the nitrogen-containing alloys increased with increasing chromium content. It was explained by the change of the deformation mechanism from strain-induced martensite transformation to another form, such as twinning or dislocation slip. Their studies, which were focused on the effect of nitrogen content, did not describe however the thick-walled castings.

This work described in this paper investigates the influence of nitrogen on the heat treatment process, what results in improved wear resistance. It concludes that in ledeburitic steels having between 0.8% and 1.2% C, addition of nitrogen may significantly reduce the need for chromium, molybdenum or vanadium content. It has tremendous impact on the economy of thick-walled castings, used especially in cement industry, where operating conditions set very demanding requirements for the extended lifetime of the rotary mill components.

2. Subject of the study and methodology of experimentation

2.1. *Background information*

The study refers to the cast steel material used for ball mill liner plates. Ball mills are commonly used in cement industry to process sintered minerals (clinker), and mix them with gypsum. The typical ball mill is a large rotating drum (about 4.5 m of diameter) containing grinding media, normally steel balls. As the drum rotates, once every couple of seconds, the motion of the balls crushes the clinker. The drum is generally divided into two or three chambers, with different size of grinding media. The walls of the chambers are waved by liners, composed of liner plates. The application of the liners increases the energy of the grinding balls and improves the efficiency of the milling process. However, during grinding the cement becomes hot, what additionally accelerates the wear of the mill elements. The object of the study, a single liner plate, is shown in Fig. 1.

2.2. *Studied materials*

The analysis compares two proposals for the material of liner plates: the standard composition of the ledeburitic steel (without nitrogen addition) – designated by the symbol ''M'', and the high carbon cast steel with nitrogen addition – marked by the symbol ''N''. The objective of the study was to driven by the fact that thick-walled structures, such as liner plates, made of standard material, may not be properly heat treated across the whole thickness.

To check the effect of nitrogen addition to high carbon cast steel, melts for research and industrial tests were prepared (Table 1).

In the alloy marked by ''N'', nitrogen dissolved in cast steel acts as a strong austenite stabilizing element, which allows its supercooling to low temperatures. In the case of analyzed cast liner plates, the delayed austenite decomposition, particularly in the temperature range of 800–650 °C, is important because it allows slower cooling during quenching. The solubility of nitrogen in high-chromium alloys is technologically sufficient. The application of chromium nitride alloys (CrN) or ferroalloys (e.g. nitrided ferrochromium, FeCrN) enables dissolving up to 0.3% of N in the steel containing 12–17% Cr. The component alloys introduced to the melted alloy were added at the end of melting process. According to the experimental results managed by authors, for a perceivable steel hardenability improvement, the optimal addition of nitrogen is in an