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Correlation between the Meyer's law parameters and the wear resistance of chromium white cast irons

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Abstract

This work studies plastic behaviour and its influence on the abrasive wear resistance of a group of high chromium white cast irons. The irons were poured in metallic moulds and heat treated. The studied alloys have 3% C, 12% Cr, as well as 0.6% and 2.4% Si. The plastic characteristics are evaluated through the parameters obtained from Meyer's test: the strain hardening capacity (n) and the constant of penetration resistance (k).

The influence of silicon content and applied heat treatments on Meyer's test parameters was determined. The heat treated samples showed values between n=2.3 and n=2.5. These values confirm a hardening capacity greater than the cast specimens. The high silicon alloy specimens show greater n-values than the low silicon alloy ones. This tendency is remarked when the complete treatments (austenitizing, cooling and holding) are applied. Correlation between n, k and the relative abrasive wear show good values for (k), but too much dispersion for the Meyer's Index (n).

Keywords: White cast iron; heat treatment; abrasive wear; strain hardening; Meyer's test.

1. Introduction

The high abrasive wear resistance and relatively good impact resistance of high chromium white cast irons (HCCI) have facilitated their frequent use for the mining and quarry industry [1-5]. The characteristics and properties of these irons have been studied, so much regarding the matrix structure [6-10], the size and orientation of the primary carbides [11,12], or their heat treatment and subsequent precipitation of secondary carbides [8,10,13-16].

Heat treatments are widely used in these foundries and alloying elements guarantee the hardenability for thick parts. Molybdenum has been the favourite addition element, also combined with nickel and copper, among others [17-19]. The use of silicon additions in these irons has been limited and it associates with low wear resistance due to the presence of perlite [5,20]. Nevertheless, silicon regulates the precipitation of carbides and the proportions in the matrix of the different phases [17,21]. Santofimia [21] pointed out the silicon content influence on the bainitic transformation and the residual austenite. Tripathy and Pattyn [18,22,23] reported the bainitic transformation as a factor for the wear resistance improvement.

Typically the hardening heat treatment of high chromium cast irons performs an austenitizing to destabilize the austenite and guarantee the desired hardenability [14,20,24]. The sub-critical treatment, done below the transformation temperature and without previous austenitizing, is attractive due to its relative low costs and good results [5,8,25].

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As reported by Dodd, Maratray and other authors [8,26-28] the solidification speed must be selected in relation with the chemical composition to obtain an appropriate microstructure. Bedolla and Rainforth [28] have reported a refinement of the structure and a secondary carbides volume increase in the 17Cr-Ni-Mo alloy, with variables amounts of Si, poured in metallic moulds. They also reported a maximum wear resistance for silicon content to be around 2%.

The strain hardening plays an important role for wear resistant applications because they are typically involved in operations with high surface loads. The addition of manganese and other alloying elements has been used to increase the austenite presence and therefore the strain hardening capacity [1,29-31], and to improve the balance between the abrasive wear resistance and the impact resistance. It is reported also that the ferrite can play a role in complex microstructures [31-33]. There are practically no references regarding the wear behaviour and strain hardening ability of other structures, particularly the ferrite or complex structures in the HCCI.

Zum Gahr [12,34], regarding the influence of the microstructure on abrasive wear, proposed a model for the two bodies abrasion. This model shows the influence on wear from the strain hardening ability of the material related to its plastic behaviour. It is demonstrated that, in spite of the similarity between the penetration test and the cutting action of the abrasive particle, the attempts of correlating the hardness with the abrasive wear have been successful only in a very general way. According to this author [35], it happens because the strain hardening has different effects on wear resistance and hardness, and also because the interactions abrasive-material are not completely characterized. Working on different matrixes, this author highlights the different situations that can be presented and concludes that the ratio of the hardness measured after and before the deformation, which is the magnitude of the strain hardening, shows a different influence on abrasive wear resistance in function of the ductility of the analysed microstructural phase. This situation remarks the importance of studying the plastic behaviour of abraded materials.

Most of the reported studies quantify the strain hardening by means of hardness measurements along a direction perpendicular to the working surface. This method evaluates the effective deformation but it is not an intrinsic property of the material, as the strain hardening capacity.

Although the strain hardening coefficient is determined performing the tensile test, it is known [36-38] that the Meyer´s Index can give an indirect evaluation of the strain hardening ability of a given material. The law of Meyer relates the loads applied with the diameter of the indentations obtained in a hardness test [37]:

$$P = k\, d^n \tag{1}$$

The value of the exponent in Eq. (1) is known as the Meyer´s Index and its values vary between 2 and 2.5, being smaller as minor is the strain hardening ability. The fractional part of the Meyer´s Index coincides with enough accuracy with the value of the strain hardening coefficient obtained from the stress-strain curve. The logarithmic expression of Eq. (1) is:

$$\ln P = \ln k + n \ln d \tag{2}$$

The value of n is determined as the slope of the regression line of the logarithmic plot. Also from the plot it is possible to evaluate the penetration resistance (k), without the influence of the strain hardening ability of the material. The line intersection on the axis of loads represents the necessary load to obtain a unitary indentation and is not affected by the strain hardening process.

This work focuses the influence of composition and heat treatment of high chromium cast irons on the Meyer´s Index (n) and the penetration resistance (k) as estimators of the plastic behaviour of these alloys. The relation between these estimators and the abrasive wear is also studied to evaluate the potential influence of the plastic behaviour on the abrasive wear resistance.

2. Materials and Methods

The studied alloys have the composition shown in Table 1. Synthetic pig-iron, ferro-chromium primary alloy and low carbon ferrosilicon were used for the melting process. A 5 kg capacity high-frequency induction furnace was used. The alloys were poured in metallic strip ingot moulds (see Fig. 1) at 1380ºC. Because the strip ingot moulds are open in the top, the heat flows mainly through the bottom of the mould and the main direction of the dendrites growth is perpendicular to the bottom surface of the mould and the strips obtained. The dimensions of the strips obtained were 15x8 mm and 250 mm long. Specimens with dimensions 15x15 mm were cut along the strip.

Fig. 1. Metallic strip ingot mould used.