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Failure analysis of a martensitic stainless steel (CA-15M) roll manufactured by centrifugal casting. Part I: Material and fractographic characterization

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ABSTRACT

The failure analysis of a martensitic stainless steel (CA-15M) roll manufactured by centrifugal casting and used in cast glass rolling was carried out by means of traditional characterization techniques (optical metallography, SEM, EDX microanalysis, tensile testing and XRD). The roll was in the as-cast condition and its microstructure featured large proportion of δ ferrite (between 20% and 27%) in a martensitic (α′) matrix, with the δ/α′ interfaces presenting an intergranular network of $M_{23}C_6$ carbides. The crack propagation began in the internal surface of the roll, with δ/α′ intergranular and transgranular cleavage in the "equiaxed region" of the casting, progressing to δ/α′ intergranular ductile fracture in the "columnar" and "chilled regions". Tensile thermal stresses in the internal surface of the roll associated with microstructural embrittlement (network of interfacial carbide and microporosities) are thought to be the main causes for the premature failure of the roll. Finally, materials selection was performed to replace the CA-15M stainless steel with another class of stainless steel for centrifugal casting.

1. Introduction

A hollow roll used as a glass roller, made of centrifugally cast CA-15M martensitic stainless steel, broke just after six rolling campaigns (three of them with 48 h of operation each). According to available information the roll finally "fractured" half an hour after withdrawing from the production line at the end of sixth campaign, during cooling in still air. The cylinder was 800 mm in length, had an external diameter of 265 mm and an internal diameter of 165 mm, with a wall thickness of 50 mm. The roll was "internally and externally machined and submitted to a stress relive heat treatment, before being chromium platted and mounted in the glass rolling equipment". The roll works in contact with molten glass at a temperature of 1100 °C and its outer surface should not exceed temperatures between 425 and 475 °C. During the glass rolling operation, the roll is cooled internally by water circulation. Within the cylinder, an aluminium core supports wood fins, whose function is to separate three different cooling zones, in which water flow can be regulated to minimize roll distortions. Also, according to information, the inner walls of the cylinders are lined with hard chromium to avoid the formation of deposits, which may reduce the cooling efficiency of the roll. According to the staff of the factory, they first identified longitudinal crack near one end of the cylinder and 15 min later two transversal cracks in regions located about 70–80% from the roll centre to its ends (see Figs. 1 and 2).

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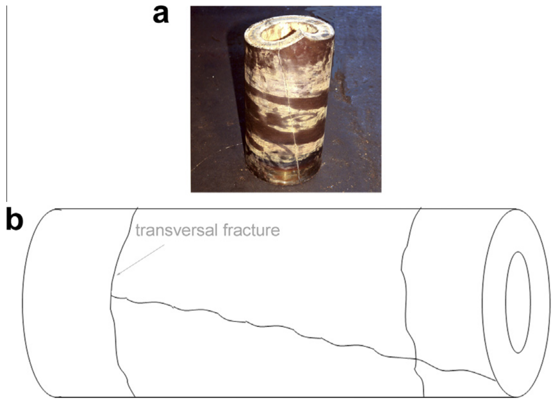

Fig. 1. (a) General view of the transversal fracture of the cylinder with the presence of a secondary longitudinal crack. (b) Scheme showing the position of the transversal and longitudinal cracks in relation to the length of the roll.

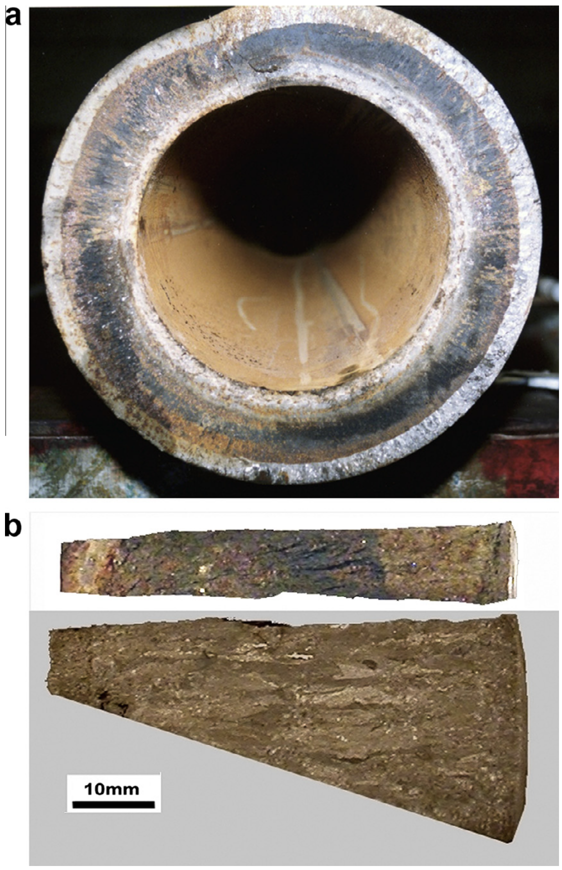

Fig. 2. (a) General view of the transversal fracture surface of the cylinder with the presence of three regions, which are roughly related to the macrostructure of the cylinder. (b) Transversal cross section, macrographic examination, shows the macrostructure evolution (after etching) during the solidification from the external surface (left) featuring chilled region (left), columnar region (centre) and equiaxed region (right) and its relationship with an old piece of the fracture surface.

2. Experimental procedure

The broken roll in the as-received condition is shown in Fig. 1a and b. Chemical analysis was carried out on samples (50 × 30 × 8 mm) close to the external and internal surfaces of the casting using optical emission spectrometer (ARL Fions, 3460 AES); C and S analyser (LECO, CS-600); and X-ray fluorescence spectrometer (Phillips, PW 2404). Tensile testing was