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Review

Investigation of failure and damages on a continuous casting copper mould

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Copper moulds are critical components in the continuous casting of steel and the surface condition of the mould directly affects the product quality and premature failure/low wear life produce a detrimental effect on the output productivity of the continuous casting machine.

This paper presents the failure analysis of a copper-based mould whose sides are coated with chromium. The performed analysis points out that the extended damage is due to two main causes: the failure origin is attributed to thermal stresses caused by working conditions and the copper wear is associated with the high zinc content of the liquid steel.

1. Introduction

Once the molten steel refining process is completed, the alloy contained in the ladle is usually sent to a continuous casting machine. The steel is poured from the ladle to a tundish and then from the tundish into a water-cooled copper mould that induces the formation of a thin, solidified steel shell (Fig. 1).

The main function of the mould is to produce and stabilize a solid shell resistant enough to contrast the metallic pressure of the liquid core and, thus, contain the liquid phase at the entry of the secondary spray cooling zone. If the mould system does not work properly, a break-out can take place and the hot liquid steel core can burst open, pouring liquid steel onto the machine and causing a very dangerous situation [1,2].

The mould is basically an open-ended box structure containing a water-cooled inner lining fabricated from a high purity copper alloy. The box can come in many shapes and sizes in order to cast different semis: blooms, billets, round beam blanks, slabs and thin slabs. A thin film of lubricating oil or of lubricating flux is interposed between the mould and the hot liquid phase to prevent its direct contact with the mould, which could potentially endanger and damage the mould itself (Fig. 1b). The surface of the copper mould coming in contact with the hot liquid metal is often plated with chromium or nickel to provide a harder working surface and to avoid copper pick-up on the surface of the cast strand, which can facilitate the development of the surface cracks on the cast product.

Maintaining a reliable, crack-free mould within close dimensional tolerances is also crucial for safety and productivity. Thus, studies [3–7] have been undertaken to better understand the complex thermal and mechanical behaviour of the mould. An extreme temperature gradient takes place across the copper plates and this causes geometrical distortions of the mould; moreover, long hours of operation at high temperatures generates creep. This resultant creep is also associated with a thermal fatigue phenomenon, which is caused by the many room temperature heating and cooling cycles undergone by the mould during the initial and final transitory of the casting sequence [3]. Some authors have attempted to simulate this

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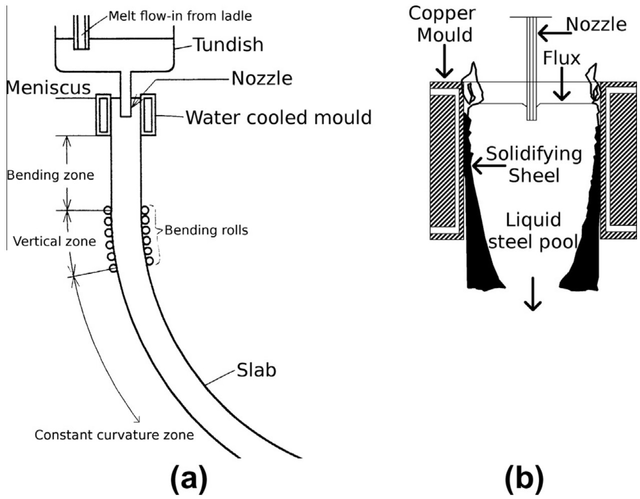

Fig. 1. Sketch of continuous casting machine (a) and mould detail (b) [1].

mechanical behaviour and to predict the potential damage to thin slag-mould systems [4,5] in order to better understand the role played by the machine dynamics in the mould damage process. In addition, friction phenomena could potentially occur between the strand and the mould. Friction between the solidifying steel and the mould is basically sliding (with a small fraction of sticky friction) [8]. These damages could end up having catastrophic consequences. At present, both metallic and ceramic plating are available [9,10]: the latter allows for an increased mould lifespan but it is not widely used due to its cost and low thermal exchange. To the contrary, metallic plating is either nickel or chromium-based. Despite its brittleness and low wear resistance, chromium is the most used metallic element in mould plating. The present study aims at illustrating the failure analysis of a copper liner, with the analysed component being a square mould made of work-hardened pure copper. The square side measures 150 mm and the mould is 1000 mm high. This particular mould was used in a continuous casting machine to produce squared billets and is only one example of the 75 different moulds affected by the same damage phenomenon.

2. Experimental procedure

Fig. 2 shows the mould under investigation. The working mould face had considerable damage in the meniscus region. After an extensive visual examination, the mould was cut into different samples in order to carry out SEM (scanning electron microscope) examination of the damaged surface. The SEM was equipped with an EDS (energy dispersive spectroscopy) probe that was used to perform local chemical analyses. Metallographic analyses were performed to characterize the mould microstructure. These analyses were realized by optical microscopy and SEM. All of the samples were prepared by grinding and polishing. Micro-etching was performed by means of an HCl solution (50 ml HCl, 5 g $FeCl_3$, 100 ml water) applied for 10 s [11]. Micro-hardness Vickers tests were performed with a 300 g load and an indentation time of 15 s.

3. Results and discussion

The examined mould showed significant damage approximately 110 mm from the mould top, at the meniscus level. This damage was even detectable from the external mould side, where the copper mould assumed a colour typical of high

Fig. 2. Failed square mould.