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On The Thermal Stress of Graphite Electrodes

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ABSTRACT

Graphite electrodes are subjected to a number of stressors in an EAF. For example, one of the limiting factors in electrode current carrying capability is the potential for thermal stress fracture, especially in the graphite near the arc. Therefore, better quantifying thermal stresses as a function of EAF conditions is critical for optimal EAF operation. Because there are no relevant standard tests, GrafTech investigated methods of heating graphite disks to quantitatively measure resistance to thermal fracture. In this work, we illustrate a connection between graphite thermal fracture and thermal loads such as electric current, with both experiments and computer simulation.

Keywords: Electric arc furnace steelmaking, graphite electrodes, temperature, thermal stress

INTRODUCTION

In electric arc furnace (EAF) steelmaking, charge material is melted by a high-powered arc that is created between graphite electrodes and the charge material. At the same time, the arc heats the portion of the graphite electrode near it. Accordingly, a complex temperature profile, leading to a thermal stress profile, develops in the electrode[1]. The magnitude of the temperature and thermal loading depends on the EAF operating conditions. They depend on, for example, whether the furnace is AC or DC, the diameter of the electrode, the magnitude and stability of the electric current, charging material and methods, etc[1]. It is over years of experience that the EAF industry has learned the general operating envelope of graphite electrodes under various EAF conditions and the relationship between electrode consumption and EAF operation[2,3]. Graphite electrodes are an integral part of the EAF electrical circuit and the reliable performance of graphite electrodes is paramount to uninterrupted and safe steelmaking.

While there is a generally accepted current carrying range for graphite electrodes as a function of electrode diameter, this is different for AC furnaces than for DC furnaces[2]. Specifically, graphite electrodes cannot carry as much current with AC than for DC for an equivalent diameter, due to the so-called skin effect[2-4]. There can also be limitations due to the so-called proximity effect[2-4]. The skin effect is caused by an induced electric field that opposes the flow of current mainly in the center of the electrode. Practically this means that most of the current is carried near the surface. In contrast, for DC the current distribution is uniform across the electrode cross section. This causes the effective resistance to be higher for AC than DC and hence the current capability to be lower. The distribution of current density is one factor impacting the electrode temperature profile due to effects from Ohmic heating inside the electrode during power-on, heat transfer within the electrode, and heat transfer from the electrode surface to within the furnace[1-4]. Additionally, besides average current level, arc stability factors into electrode consumption[3].

Among additional factors besides electric current - removing an electrode from the furnace, such as for a bucket charge, or to make an electrode add, expose the hot electrode to the cooler environment, leading to thermal shock loading.

To better understand and improve electrode consumption, GrafTech has long standing efforts concerning the fundamental factors at work in an EAF, including findings previously presented at AISTech conferences[1-3,5-9]. Regarding graphite electrode performance in particular, there remain a number of gaps in the understanding. Part of this is that there are complicated multiphysics interactions between the EAF environment and the electrode and part of this is due to the complicated character of electrode graphite. The usefulness of manufactured graphite as a material for electrodes in an EAF is that its strength does not decrease with increasing temperature, that it has excellent thermal shock resistance. low chemical reactivity, and good electrical conductivity.

