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# Phase and microstructural evolution of low carbon MgO-C refractories with addition of Fe-catalyzed phenolic resin

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ABSTRACT

In the present paper, phase and microstructural characterization of low carbon MgO-C refractories with addition of Fe-catalyzed phenolic resins as binder were investigated. Initially, phenolic resin was modified using various amounts of Fe particles as catalyst originated from iron nitrate ([$Fe(NO_3)_3 \cdot 9H_2O$]). The MgO-C matrix compositions were prepared by using 7% of modified phenolic resin, shaped and cured at 200 °C for 24 h. The cured samples were coked in the temperature range from 800 to 1400 °C and then characterized by XRD and FE-SEM techniques. Based on attained results, in-situ graphitic carbons, particularly in carbon nanotubes (CNTs) network were gradually formed from Fe-catalyzed phenolic resin in the matrix of MgO-C refractory bodies. It was also clarified in comparison with sample containing as-received phenolic resin, more ceramic whiskers such as $Al_4C_3$, AlN, MgO and $MgAl_2O_4$ were formed in the matrix of MgO-C specimens with addition of Fe-catalyzed phenolic resin binder and significantly increased with coking temperature. Microstructural observation showed the graphitic carbons like CNTs and ceramic whiskers mainly formed in the bonding phase between the aggregates, that certainly leads to enhancement of physical and mechanical properties of MgO-C refractories.

## 1. Introduction

MgO-C refractories (MCRs) are widely used as a high duty material in steelmaking industries, due to their excellent properties such as thermal shock resistance, corrosion resistance and ultimately their high operating life [1]. The presence of carbon in MCRs enhances corrosion resistance property due to the non-wettability against the molten metal and slag and improves thermal shock resistance because of high thermal conductivity of carbon, which saves the refractory structure from continuous thermal shock damages during operation [2,3]. Conventionally, MCRs contain 8–20 wt% of carbon, which associated with disadvantages such as low oxidation resistance, high heat loss, lower mechanical strength at high temperature, higher carbon pick-up in molten steel and generation of higher extend of $CO_x$ gases [4,5]. Therefore, various studies have been focused to develop low carbon MCRs in recent years. However, the decrease of the carbon content usually accompanied by a reduction in thermal shock resistance and flexibility and $K_{IC}$ of MCRs when exposed to severe thermo-mechanical stresses [6]. Recently, to overcome these problems, a lot of works has been made to use nano-carbon sources like carbon nanotubes (CNTs), graphene or graphite oxide nano-sheets (GONs), nano carbon black (CB), which has led to develop of the nano structural matrix with improved properties in carbon containing refractories [7–9]. Despites the results have shown that the effective influence of nano-carbon materials on physical and thermo-mechanical properties of MCRs, it should be recognized that nano size carbon materials are cost-effective and also homogenous dispersion of as-received nano-carbon is still huge challenge for the application in refractory industry.

The very new revolutionary explained by some researchers that improve the performance of MCRs through the formation of in-situ nano-carbon structures and new ceramic bonding phases in the matrix of carbon containing refractory bodies [10–12]. The in-situ development of nano-carbon and ceramic fibers reinforce the matrix and improve thermo-mechanical properties of refractories. Aneziris et al. [13] found that nano $TiO_2$ addition could lead to the formation of TiCN and TiC whiskers in the matrix of MCRs. These ceramic phases can improve oxidation resistance and mechanical strength significantly. Bag et al. [14] develop a new low carbon MCRs with addition of nano carbon block. Their results showed the addition of low content carbon block reduces porosity, increase densification, strength and corrosion resistance. Again nano carbon block also absorbs and relieves the stresses and improves thermal shock resistance. Although, addition of nano

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