

# 软熔带类型对高炉内未燃煤粉分布影响的数值模拟

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**摘 要:** 为了改善高炉炉况、降低未燃煤粉对高炉的负面影响,利用“Euler-Euler”法对高炉内未燃煤粉的堆积分布进行了数值模拟.考察了倒V型、V型和W型软熔带高炉内的未燃煤粉分布,以及软熔带形状对未燃煤粉分布的影响,并比较了三种软熔带高炉堆积未燃煤粉量的多寡和高炉各区域未燃煤粉堆积量.计算结果表明:未燃煤粉主要堆积在高炉软熔带下方;死料柱、风口回旋区下方、软熔区域、软熔带顶部和根部是未燃煤粉容易堆积的区域.W型软熔带是最佳的高炉操作模式,具体表现在:未燃煤粉在高炉内分布相对均匀;在一定压差条件下可容纳较多煤粉.

**关 键 词:** 软熔带;高炉;未燃煤粉;数值模拟;炼铁

**中图分类号:** TF 512      **文献标志码:** A      **文章编号:** 1005-3026(2018)09-1242-06

## Numerical Simulation for the Influence of Cohesive Zone Shape on Distribution of Unburned Pulverized Coal in Blast Furnace

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**Abstract:** In order to improve blast furnace (BF) operation and reduce the negative influence of unburned pulverized coal on BF performance, the "Euler-Euler" method was used to simulate the distribution of unburned pulverized coal in BF. The distribution of unburned pulverized coal in BF with three kinds of cohesive zone and the influence of cohesive zone shape on the distribution of unburned pulverized coal were investigated. For different cohesive zones, the total amount of unburned pulverized coal and the regional accumulation amount of unburned pulverized coal were compared. The simulation results show that the unburned pulverized coal is mainly accumulated below the cohesive zone of BF. The deadman, the region below the raceway, the cohesive area, and the top and root of the cohesive zone are the main regions where the unburned coal powder easily accumulates. The W-shape cohesive zone is the best blast furnace operation mode. The reasons are: the distribution of unburned pulverized coal in BF is relatively uniform; more pulverized coal can be accommodated under a specific differential pressure condition.

**Key words:** cohesive zone; blast furnace; unburned pulverized coal (UPC); numerical simulation; ironmaking

未燃煤粉在高炉内可参加铁水渗碳、碳气化反应和还原反应,但随着高炉喷煤量的提高,若未燃煤粉堆积量超过了高炉内部反应消耗的量,未燃煤粉将在高炉内部堆积,影响高炉透气性,使压差升高,严重时影响高炉顺行;因此未燃煤粉在高炉内的过量堆积是限制高炉喷煤量的重要因素之一<sup>[1-3]</sup>.

为了改善高炉炉况、降低未燃煤粉对高炉的负面影响,有必要对未燃煤粉在高炉内的分布进行研究.国内外学者对高炉内未燃煤粉的运动分布作了相应的研究.文献[4-5]分别通过物理模拟的方法研究了喷吹一定量煤粉后,煤粉在高炉



软熔带矿石层设定为气体和未燃煤粉不能通过的区域. 软熔带参数的定义如图 1 所示. 倒 V、V 和 W 型三种高炉软熔带的参数见表 1.

表 1 软熔带参数				
Table 1 Parameters of the cohesive zone				
形状	$H/\text{m}$	$D/\text{m}$	$\alpha/(\text{^\circ})$	$\beta/(\text{^\circ})$
倒 V	5.1	3.05	51	—
V	5.1	3.05	—	53
W	3.9	4.25	51	52

1) 高炉各区域及空隙度参数. 将高炉模型分为块状带、软熔带“焦窗”、滴落带、死料柱和风口回旋区 5 个区域(见图 2). 根据文献[13], 从料面到风口间的高炉平均空隙度在 0.231 ~ 0.426, 高炉块状带的空隙度在 0.35 ~ 0.46, 因此将高炉块状带、软熔带“焦窗”、滴落带、死料柱和风口回旋区的空隙度  $\varepsilon_1, \varepsilon_2, \varepsilon_3, \varepsilon_4, \varepsilon_5$  分别设为 0.4, 0.35, 0.3, 0.25, 1.0.

将高炉模型从炉喉沿径向分为三等分(如图 2 所示), 即高炉模型分为三个区域: 中心区域、中间区域和边缘区域, 以便于比较未燃煤粉在高炉模型各区域的堆积分布.

2) 物性参数. 高炉模型中的填充颗粒球形度均设为 0.75, 颗粒直径为 0.025 m; 气体为 1.01 ×

10<sup>5</sup> Pa 下 20 ℃ 的空气; 烟煤和无烟煤的密度分别为 1 250 ~ 1 500 kg·m<sup>-3</sup>, 1 360 ~ 1 800 kg·m<sup>-3</sup>[1]; 本研究选取未燃煤粉密度为 1 400 kg·m<sup>-3</sup>, 气体和煤粉的物性参数及模拟高炉的基本操作参数见表 2.

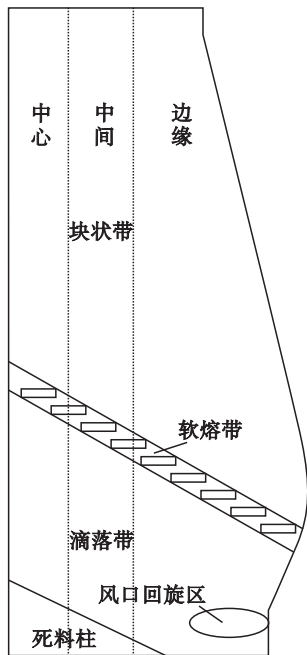


图 2 高炉区域空隙度示意图  
Fig. 2 Schematic illustration of regional porosity in blast furnace

表 2 计算参数及高炉操作参数			
Table 2 Calculation and operation parameters of blast furnace			
计算参数		操作参数	
数值		数值	
未燃煤粉直径/m		产量/(t·d <sup>-1</sup> )	
$7.5 \times 10^{-5}$		3 200	
风口气体速度/(m·s <sup>-1</sup> )		风量/(m <sup>3</sup> ·min <sup>-1</sup> )	
218		2 389	
风口煤粉喷吹量/(kg·m <sup>-2</sup> ·s <sup>-1</sup> )		喷煤比/(kg·t <sup>-1</sup> )	
2.21		158	

### 1.4 数值模拟的验证

采用 1:25 比例的高炉二维模型, 通过比较中心线压差来验证数学模型的正确性, 高炉模型几何尺寸及测压点如图 3a 所示.

由图 3b 可以看出, 计算值与实验值的趋势基本吻合. 因此数学模型能较好地模拟高炉填充床模型中气固两相流的运动.

## 2 计算结果与讨论

### 2.1 不同软熔带形状下未燃煤粉的分布

软熔带的形状是高炉上下部调剂的综合体现, 主要受布料制度和送风制度的影响, 是决定高

炉煤气流稳定运行的关键. 在相同喷吹条件下, 三种软熔带形状下高炉内未燃煤粉的堆积分布如图 4 所示. 由图可知: 1) 高炉块状带的未燃煤粉堆积量较少, 未燃煤粉主要堆积在高炉软熔带下方; 死料柱、风口回旋区下方、软熔区域是未燃煤粉易堆积的区域; 2) 软熔带形状对软熔区域及死料柱上的未燃煤粉的分布有重要影响: 倒 V 型软熔带高炉中, 未燃煤粉易在软熔区域的中心堆积; V 型软熔带高炉中, 未燃煤粉在软熔区域的边缘容易堆积, 在死料柱上方未燃煤粉的堆积量较多; W 型软熔带高炉中, 未燃煤粉在高炉软熔区域的中心和边缘的堆积比较分散, 显著堆积的区域较少, 未燃煤粉在软熔区域的分布相对均匀.





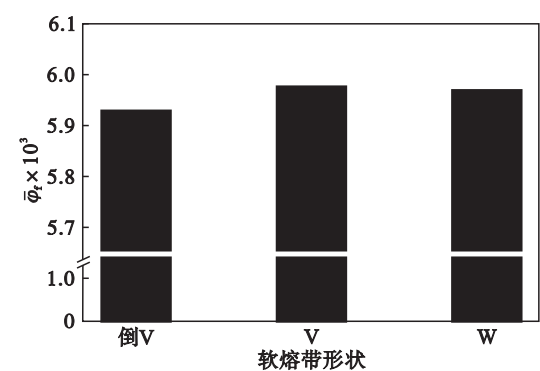


图 6 不同软熔带形状高炉内未燃煤粉平均体积分  
Fig. 6 Average volume fraction of UPC in blast furnaces with different cohesive zones shape

将高炉沿垂直高度划分为若干层,每层分为中心、中间和边缘三个区域,通过平均体积分数比较高炉模型各部位的未燃煤粉堆积量.图 7 为三种软熔带高炉分层区域的未燃煤粉平均体积分数.由图可见,三种软熔带高炉的块状带和炉缸区域未燃煤粉平均体积分数基本一致,即未燃煤粉堆积量基本一致.在软熔带及其根部和上部区域,未燃煤粉平均体积分数相差较大,说明软熔带形状对该区域未燃煤粉的分布影响较大.在三种软熔带高炉的中心和中间区域,倒 V 型高炉堆积的未燃煤粉量较多,其次是 W 型和 V 型高炉;而在边缘区域,与之相反.因此比较三种软熔带高炉, W 型软熔带高炉的未燃煤粉在软熔带区域径向分布相对均匀,这也是 W 型软熔带的高炉操作优势之一.

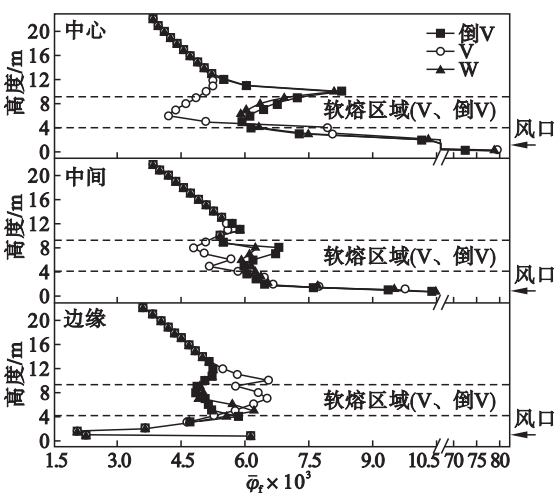


图 7 高炉各区域未燃煤粉的平均体积分  
Fig. 7 Average volume fraction of UPC in various regions of blast furnace

2.3 不同软熔带形状下高炉内部压差分布

图 8 为三种软熔带高炉在高炉中心线上的压差分布(以高炉出口压力 101 325 Pa 为基准压力,

以风口水平线为起点).由图可见:1)在高炉块状带区域,三种软熔带高炉的压差分布无显著差别;2)高炉软熔带的形状对高炉中心压差的影响主要在软熔带区域,V 型软熔带压力分布不均,这是高炉操作不选择 V 型软熔带的原因之一.

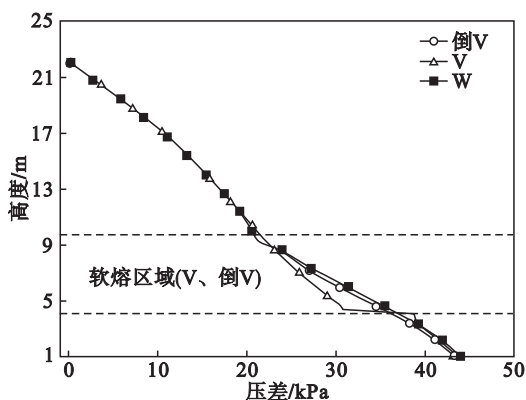


图 8 不同软熔带形状高炉的中心压差  
Fig. 8 Pressure difference distribution along the center line of the BF with different cohesive zone shape

3 结 论

- 1) 软熔带形状对高炉内未燃煤粉分布的影响主要在软熔带及其根部和上部区域.未燃煤粉主要堆积在高炉软熔带下方,死料柱、风口回旋区下方、软熔区域是未燃煤粉最容易堆积的区域.
- 2) 三种软熔带中, W 型软熔带是最佳的高炉操作模式,具体表现在:①未燃煤粉在高炉内分布相对均匀;②在一定压差条件下可容纳较多煤粉.

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