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论文

高频电磁场对15CrMo连铸坯表面质量和等轴晶率的影响机理

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摘要:

采用小线圈法对结晶器内的磁场分布进行了测量, 并对结晶器内磁场、电磁力和钢液流速分布进行了数值模拟. 在实验室连铸机上进行了合金结构钢15CrMo的连铸实验, 对连铸坯表面形貌进行了观察与分析. 提出了高频电磁场对连铸坯质量影响的机理: 施加高频电磁场后, 保护渣通道拓宽, 铸坯与结晶器壁间的渣道动压减小, 有效地抑制了铸坯表面振痕的产生; 受电磁场Joule热以及保护渣热增加的影响, 已结晶固相的温度梯度减小, 柱状晶生长受到抑制. 此外, 实验测量和数值模拟结果表明, 由于磁场在拉坯方向分布不均匀, 在弯月面区域形成上、下2个方向相反的涡流, 钢液环流造成固/液界面前沿液相的温度梯度减小, 有利于形成成分过冷而获得发达的等轴晶组织.

关键词: 连铸 结晶器 振痕 保护渣压力 等轴晶 成分过冷

EFFECT MECHANISM OF HIGH FREQUENCY ELECTROMAGNETIC FIELD ON THE SURFACE QUALITY AND EQUIAXED CRYSTAL RATIO OF 15CrMo BILLET

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Abstract:

An induced coil surrounding a segmented mold used in soft--contact electromagnetic casting (soft-contact EMC) was used to produce a high frequency magnetic field for reducing ferrostatic pressure between the mold and melt. The distribution of magnetic field in the mold was examined using a magnetic
probe of the induction coil type. Then mathematical model was developed to study the distributions of magnetic field, electromagnetic force and flowing velocity of molten steel in the mold. Finally, continuous casting
experiments were conducted with alloy constructional steel 15CrMo in the laboratory caster. The surface morphologies and macrostructure were examined and analyzed. Based on the comprehension of the distributions of magnetic field, electromagnetic force and flowing velocity of molten steel in the mold through
measurements and numerical simulation, the effects of electromagnetic field were systematically investigated.
The results indicate that when the electromagnetic field was applied in the initially solidified area, the mold flux consumption was increased dramatically. As a result, the surface quality of continuously cast billets is greatly improved, for example, oscillation marks disappeared due to the decrease of flux pressure. Moreover, the
growth of columnar grains is suppressed for two main reasons. The first one is that the mold near meniscus is
heated by Joule heat generated by the high frequency electromagnetic field. The other one is that the thermal
resistance between mold and the solidified shell is increased as the increase of mold flux thickness. Inhomogeneous distributions of magnetic field in the mold along the casting direction were confirmed both by
measurement and numerical simulation. And the Lorentz force on the molten steel along the casting direction is
uneven likewise. Under the drive of Lorentz force, two counter-rotational vortices are formed below the meniscus. Moreover, the temperature gradient in front of the solid/liquid interface is decreased as a result of the
circulation of liquid steel. Therefore, composition supercooling is easily obtained in the liquid core, which is

helpful to the growth of equiaxed crystals.

Keywords: continuous casting mold oscillation mark mold flux pressure equiaxed grain composition supercooling

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参考文献：

[1] Viv`es C. Metall Trans, 1989; 20B: 623
[2] Asai S. Electromagnetic Processing of Materials. Tokyo: ISIJ, 1989: 51

(浅井滋生. 电磁気を利用したマテリアルプロセッシング. 东京: 日本铁钢协会编, 1989: 51)

[3] Miyoshino I, Takeuchi E, Yano H, Sakane J, Saeki T, Kajioka H. ISIJ Int, 1989; 29: 1040
[4] Kim H, Park J, Jeong H, Kim J. ISIJ Int, 2002; 42: 171
[5] Li T J, Sassa K, Asai S. ISIJ Int, 1996; 36: 410
[6] Toh T, Takeuchi E, Hojo M, Kawai H, Matsumura S. ISIJ Int, 1997; 37: 1112
[7] Nakata H, Inoue T, Mori H, Ayata K, Murakami T, Kominami T. ISIJ Int, 2002; 42: 264
[8] Park J, Jeong H, Kim H, Kim J. ISIJ Int, 2002; 42: 385
[9] Park J, Kim H, Jeong H, Kim G, Cho M J, Chung J, Yoon M, Kim K R, Choi J. ISIJ Int, 2003; 43: 813
[10] Zhou Y M, Zhang Y J. Baosteel Technol, 2003; (1): 1
(周月明, 张永杰. 宝钢技术, 2003; (1): 1)
[11] Xu X J, Deng A Y, Wang E G, Zhang L T, Zhang X W, Zhang Y J, He J C. Acta Metall Sin, 2009; 45: 464
(许秀杰, 邓安元, 王恩刚, 张林涛, 张兴武, 张永杰, 赫冀成. 金属学报, 2009; 45: 464)

[12] Cai K K, Cheng S F. Fundamentals and Technology of Steel Continuous Casting. Beijing: Metallurgical Industry Press, 1994: 86
(蔡开科, 程士富. 连续铸钢原理与工艺. 北京: 冶金工业出版社, 1994: 86)

[13] Yu G W, Jia G L, Wang E G, He J C, Zhang Y J, Chen Z P. Acta Metall Sin, 2002; 38: 208
(于光伟, 贾光霖, 王恩刚, 赫冀成, 张永杰, 陈兆平. 金属学报, 2002; 38: 208)

[14] Lei Z S, Ren Z M, Yan Y G, Deng K. Acta Metall Sin, 2004; 40: 550
(雷作胜, 任忠鸣, 阎勇刚, 邓 \ \ 康. 金属学报, 2004; 40: 550)
[15] Takeuchi E, Brimacombe J K. Metall Trans, 1984; 15B : 493
[16] Thomas B G, Zhang L. ISIJ Int, 2001; 41: 1181
[17] Winegard W C, Chalmers B. Trans Am Soc Met, 1954; 46: 1214
[18] Jackson K A, Hunt J D, Uhlman D R, Seward T P. TMS–AIME, 1966; 236: 149
[19] Southin R T. TMS–AIME, 1976; 239: 220
[20] Ohno A. The Solidification of Metals. Chijin: Shokan Co., Ltd., 1976: 50
[21] Zhang Y J. PHD Thesis, Northeastern University, Shenyang, 2005
(张永杰. 东北大学博士学位论文, 沈阳, 2005)
[22] Deng A Y, Wang E G, He J C. J Iron Steel Res, 2002; 14: 6
(邓安元, 王恩刚, 赫冀成. 钢铁研究学报, 2002; 14: 6)
[23] Ren Z, Dong H, Deng K, Jiong G. ISIJ Int, 2001; 41: 983
[24] Cui Z Y, Qin Y C. Metal Science and Heat Treatment. Beijing: China Machine Press, 2007: 82
(崔忠圻, 覃耀春. 金属学与热处理. 北京: 机械工业出版社, 2007: 82)

[25] Hu H Q. Metal Solidification Theory. Beijing: China Machine Press, 2007: 120
(胡汉起. 金属凝固原理. 北京: 机械工业出版社, 2007: 120)

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2．黄军涛, 赫冀成 .方坯结晶器内钢液凝固及电磁制动的数值模拟[J]. 金属学报, 2001,37(3): 281-286

3．李双明, 刘林, 李晓历, 傅恒志 .包晶合金定向凝固平界面前沿的形核分析[J]. 金属学报, 2004,40(1): 20-26

4．钱忠东, 吴玉林 .连铸结晶器内钢液涡流现象的大涡模拟及控制[J]. 金属学报, 2004,40(1): 88-93

5．沈明钢, 金山同 .钢初期凝固坯壳的自由变形[J]. 金属学报, 2000,36(10): 1104-1108

6．文光华, 祝明妹 .双辊薄带连铸熔池液面波动物理模拟[J]. 金属学报, 2000,36(9): 1001-1004

7．董杰, 刘晓涛, 赵志浩, 包卫平, 崔建忠 .结晶器材料对低频电磁铸造超高强铝合金铸态组织的影响[J]. 金属学报, 2004,40(2): 215-219

8．赫冀成 .流动控制结晶器磁场分布的实验测试[J]. 金属学报, 2000,36(9): 1005-1008

9．樊俊飞, 朱苗勇, 张清朗, 王文忠 .六流连铸中间包内流动与传热耦合过程的数值模拟及控流装置优化[J]. 金属学报, 1999,35(11): 1191-1194

10．雷作胜, 任忠鸣, 闫勇刚, 邓康 .高频调幅磁场下无结晶器振动电磁连铸技术的实验研究[J]. 金属学报, 2004,40(9): 995-999
