INFLUENCE OF RARE EARTH METALS ON MACROSTRUCTURE OF CONTINUOUSLY CAST STEEL ROLLING PIPE

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ABSTACT

The influence of Rare earth metals (RE) on macrostructure of continuously cast steel ingot have been studied in the full-scale industrial trials. The results can be described as follows: RE addition reduced macrosegregation, enlargement of equiaxed zone and reduced loose structure. The centerline ingot segregation was expanded. The length of segregation line was distributed. RE sulphides were mainly precipited in dendrite arms. These results were compared with CaSi treatment.

I. INTRODUCTION

Effect of RE on solidification macrostructure of cast steel ingot rolling pipe is very important not only for rollability but also for improving quality of pipeline products [1-13]. The RE addition to steel influences dendritic arm spacing, length and growth direction of dendrite arm. This also refines as-cast structures, reduces segregation and increases rollability, since RE addition can reduce macrosegregation, enlargement of equiaxed zone and reduced loose structure. It can also form the V-segregation moving toward the center of continuously cast ingot and expand the segregation area. The length of segregation line and the segregation ratio are reduced [13-17]. Recently there were many works studying on the addition of RE in continuously cast steel[18-25]. Most of them concentrated as sulphides and oxides of RE and are distributed in V-segregation of continuously cast ingot [4-12, 26-32].

The aim of the present work describes the effect of injecting RE on sulphur print and macrostructures of commercial continuously cast ingots for over 400T pipeline steel.

II. BASIC CONSIDERATION OF ON MACROSTRUCTURE

Rare earth metals have proved to have such effects on the macrosolidification structure as on the quantity equiaxed crystals and macrosegregation. Most recent works have shown that the addition of alloying element forms equiaxed crystals by the following three factors: a) an increase in constitutional supercoolling [28] b) acceleration of heterogeneous nucleation c) separation of dendritic arms [29]. The authors proved that the factors a) and c) do not hold good, because the amount of RE addition is very small.
Also dissoved sulphur, which lowers the melting point of steel. is converted into compounds and the dendrite arms grow in compact rather than coarsened form [32,34].

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The heterogeneous nucleation

The heterogeneous nucleating abilities of $(RE)_2O_3$ and (RE)S [18] .The solute concentration distibution on the liquid side at the solid-liquid interfaces is expressed as follows [34] :

$$C_L = C_S \{(1 / k_o - 1) . \exp(-f.x / D) + 1 \} \quad (1)$$

Where: C_L is the concentration of solute in liquid phase

C_S is the solute concentration in solid phase

D is the diffusion coefficient of solute

x is the distance from the solid-liquid interfaces

k_o is the equilibrium distribution coefficient

According to author Nuri [33] supercooling temperature ΔT in front of the solid-liquid interfaces is determined as follows:

$$\Delta T = m C_S / k_o - m C_S (1 / k_o - 1 / k_e). x / \delta - m C_S \{(1 / k_o - 1).\exp(-f. x / D) + 1\} \quad (2)$$

Where: k_e is the equilibrium distribution coefficient at liquid temperature

δ is the boundary film thickness

In cosidering the effect of the superheating temperature ΔT_H of molten steel, correction must be made by the following equation:

$$\Delta T_{H(x)} = \Delta T_H . \{1 - (d / d_o)^2\}. x / \delta \quad (3)$$

where: d_o is 1/2 the thickness of continuously cast ingot

d is the shell thickness

Heterogeneous nucleation takes place throughout the entire solidification period in the RE added steel, which in the RE free steel, it is limited to the early and closing stages of solidification.

Effects of RE on macrosegregation

The interdendritic flow consists only of a component that is perpendicular to the isothermal line and the interdendritic flow rate V_x relating solidification rate f can be expressed as follows[33]:

$$V_x / f = - (\beta / 1 - \beta) \quad (4)$$

where: β is the coefficient of volume contration on solidification, if the value of V_x / f becomes larger than the right hand side term in equation (4) microsegregation can occur; this means reduction of macrosegregation, especially the inverted V-segregation. Most studies [26-28] showed that the RE additions reduce the dendrite arm spacings and the gravitational convection, whereby the interdendritic flow is weakened, the formation of the inverted V-segregate are restrained, and its shape distribution thereof improved.

III. EXPERIMENTAL METHOD

The experimental samples were all prepared from steels for rolling pipe melted in a 45T electric arc furnace. The FeSiRE cored wire (with composition shown in **table 1**) 11mm in diameter was used as RE on RE-CaSi injection station.

Table 1. FeSiRE composition

Si	Ca	Mg	RE	Al
45.20	4.30	0.90	21.60	7.20

The samples for chemical analysis without and with RE and CaSi (for comparing) addition were done. Cut pieces were subjected to sulphur printing and macroetching test. The sulphur prints were tested by Baummann method [35] and appear in photograph's papers with brown prints of Ag_2S. The macroetching samples were treated in chloride solution [35] and gained photographs.

The conditions of the test steels were shown in **table 2.**

Table 2. Experimental condition of continuously cast ingots

Sample No	Chemical analysis (w%)								RE/CaSi addition /kg/t/	Other
	C	Si	Mn	P	S	Al	RE	Ca		
1. 1806	0.11	0.38	0.28	0.017	0.017	0.005	-	0.0005	0.5CaSi	compare
2. 1807	0.12	0.40	0.27	0.020	0.020	0.023	-	0.0005	1.1CaSi	compare
3. 1808	0.17	0.57	0.34	0.029	0.019	0.020	<0.0002	0.0005	0.01RE	
4. 2106	0.13	0.51	0.26	0.023	0.021	0.016	<0.0002	0.0005	0.02RE	
5. 1815	0.16	0.56	0.29	0.026	0.020	0.016	<0.0002	0.0010	0.03RE	
6. 2107	0.17	0.44	0.31	0.015	0.012	0.011	<0.0002	0.0005	0.05RE	
7. 2113	0.15	0.32	0.31	0.016	0.026	0.007	<0.0002	0.0007	0.07RE	
8. 2114	0.17	0.40	0.31	0.016	0.015	0.013	<0.0002	0.0005	0.10RE	
9. 1799	0.12	0.39	0.36	0.020	0.020	0.023	0.0070	0.0008	0.20RE	

IV. RESULTS AND DISCUSSION

The results of sulphur prints are shown in **figure 1**

The sulphur prints clearly reveals the existence of macrosegregation in ingots. Samples 8.2114 and 9.1799 had very less sulphuide inclusions, where sulphur segregated very differently. Ingots 3.1808, 4.2106 and 5.1815 exhibited a positive segregation of sulphur. Ingots 6.2107 and 7.2113 sulphide inclusion were accumulated, suggesting that the grouped inclusions contained sulphide-base inclusions vis-a-vis ingots 8.2114 and 9.1799 were homogeneous, exhibiting only localized segregation.

Figure1(2) and 1(4) show the centerline segregation in RE added and RE free continuously cast ingots. The centerline segregation decreased with increasing amount of RE.

The results of macrostructure are shown in **figure 2.** RE addition tended to decrease the length of segregation. RE exhibited positive segregation, but the degree of segregation decreased as the quantity of RE addition increased in order of samples 3.1808 with 0.01kg/t to 9.1799 with 0.2 kg/t. Here there were some differences, in gained photographs. The RE addted steels are formed to shorten of the primary dendritic arm spacing (**figure 2 2**.1807, **5**.1815, 7.2113 and **9**.1799) and reduce in macrosegregation.

Figure 3 was shown that with increasing amount of RE addition into steel, will be decreased primary dendritic arm length in macrosegregation from 26 mm to 18 mm.

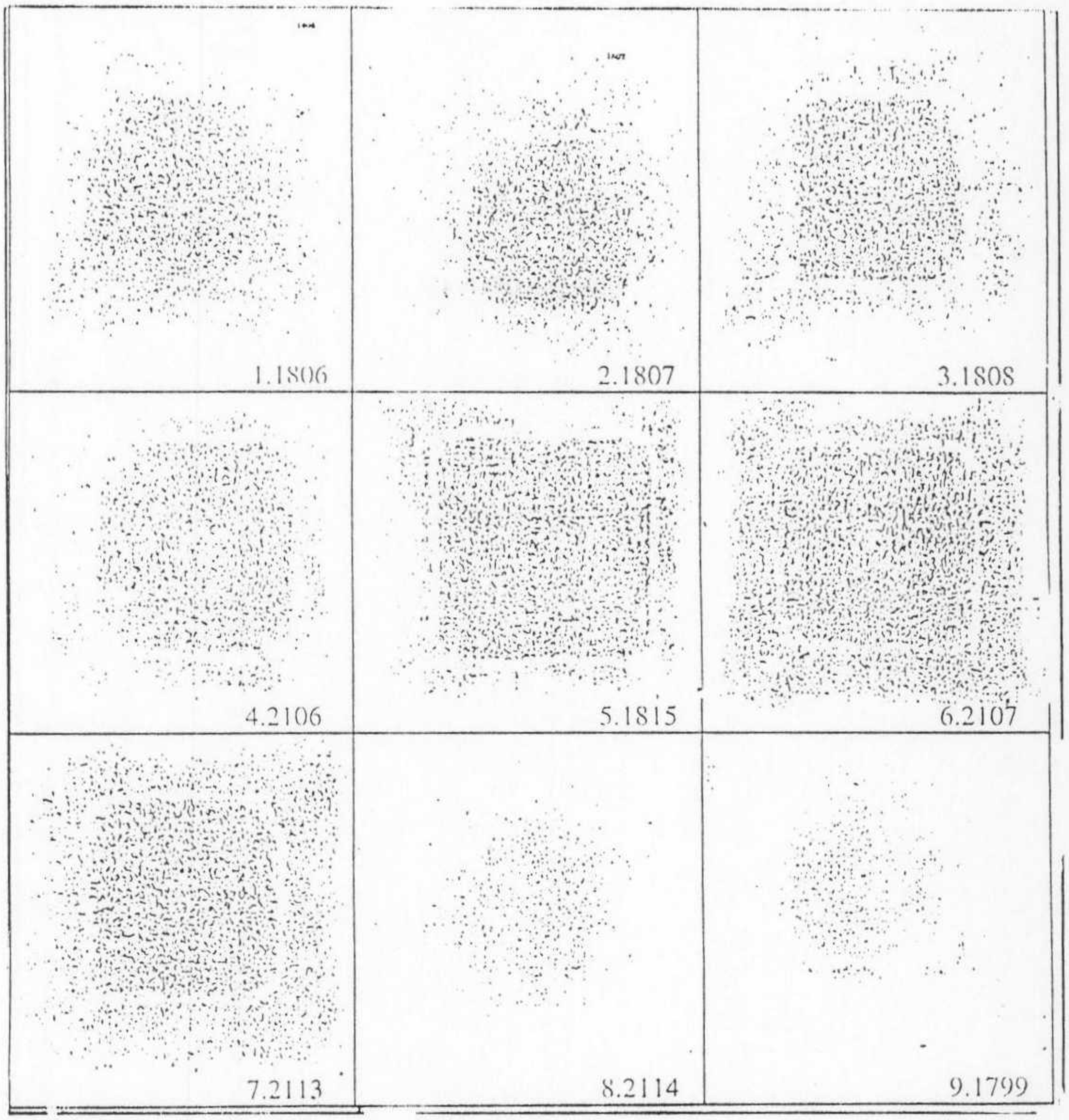

Figure 1. The sulphur prints of continuously cast ingots treating RE and CaSi

The RE added steels in samples 2.1808 to 8.2114 (**figure 2**) showed that primary dendritic arm spacing was very narrow and primary dendritic arm length was shorter comparing with CaSi treatment. The growth direction of dendritic arm is less oriented. Thus the considerations cited above have been found to be proved in 7 samples containing RE and comparing with 2 samples treating CaSi.

The effect of RE additions on the macrosolidification structure is a) reduction in the primary arm spacing, affecting the depth of permeation of the flow in interdendritic region. b) reduction in the centerline and other macrosegregation. This finally results in the hidden scab defect inside pipe leading to leak especially in oil pipes.

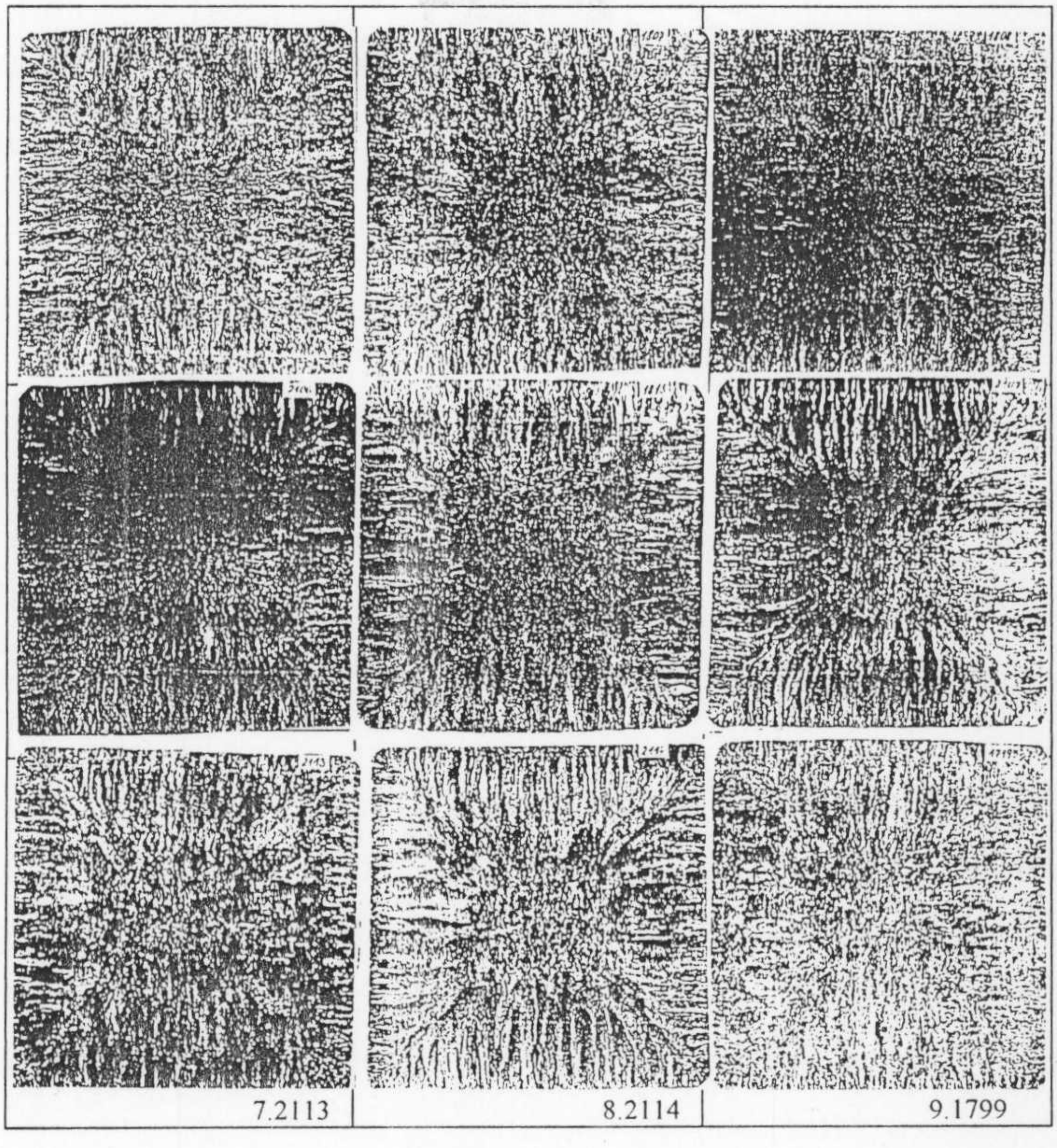

Figure 2. The macrostructure of continuously cast ingot treating RE and CaSi

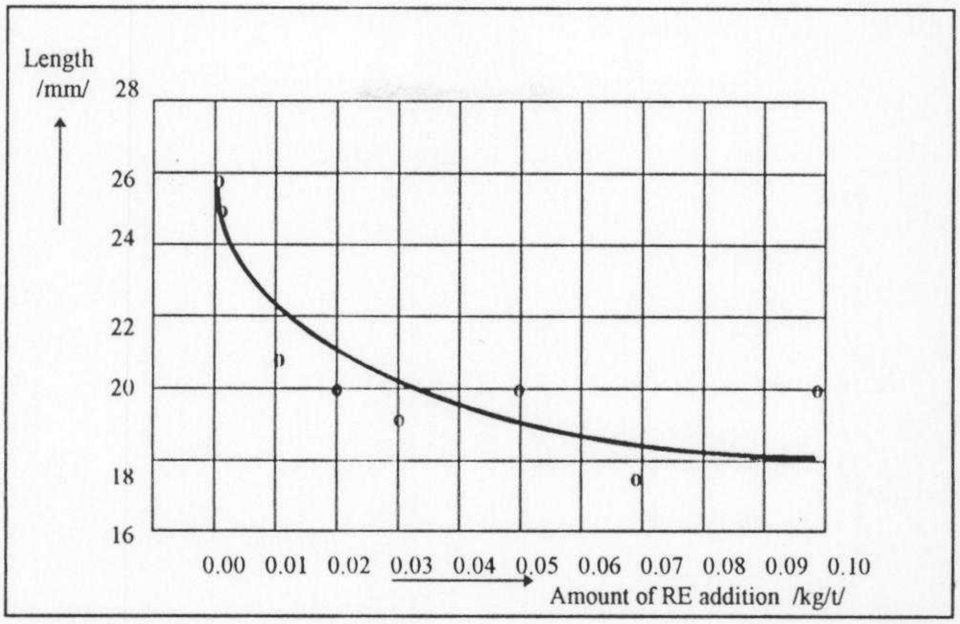

Figure 3. Relationship between the amount of RE addition and primary dendritic arm length

V. CONCLUSIONS

i) Rare earth metals have ability to refine as-cast structures of continuously cast steel.

ii) Quantity of sulphur in steel reduces gradually with increase of the amount of RE addition, the centerline sulphur segregation decreased.

iii) RE affects reduction in macrosegregation and decreases loose structure

iv) The RE additions reduced primary dendritic arm spacing, shortened dendritic and interdendritic arm length in steel ingots.

v) The comparision with CaSi treatment wasn't clarified and needs further investigation.

AKNOWLEDGEMENTS

The author is thankful to Professor, P. Ramachandra Rao, the Director, National Metallurgical Laboratory - Jamshedpur for providing all facilities and encouragement for this work . I am also grateful to Dr. P.K. Biswas Sr. Scientist; MTP Division of this Laboratory for valuable discussions and help in preparing this manuscript.

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