Effects of M-EMS Magnetic Field Intensity on MnS Precipitate in Rail

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Abstract. The process contrast tests with M-EMS stirring intensity was carried out, MnS inclusion scanned and statistics with Aspex, make comparison among the different process for the same testing area after conversion and unified the results that about the length of single inclusion and ratio of inclusion area. Result shows possibility of big size pure MnS separate increased with the greater stirring intensity; besides, nucleation possibility of compound state MnS increased, formation of bigger size compound MnS was promoted at the same time. Conclude that add nucleating agent while smelting and choose 210Gs as the proper stirring intensity is helpful for MnS inclusion separate control, and improve the technological level of inclusion control in rail at last.

1. Introduction
Purification of steel have been an important project all the time, plenty of research work was carried out to analyze the specific effects of inclusion on steel\(^{[1-6]}\), different inclusion type have different effect on material property, while the same effect could be found that inclusion cut off the continuity of basic structure which lead anisotropy for steel. One type of the inclusion is type A that is sulfide, and MnS is the mainly chemical component, which could be draw out to be strip while rolling with the large compression ratio. And then blowhole segregation or combine with hot crack appeared, generally it’s appeared with phosphorus and manganic segregation, and which caused by different shrinkage lever between inclusion and basic. That lead internal crack appeared and weaken the hardness and toughness of rail at last, and performance life tend to be decreased as the result. Therefor A type inclusion tend to be strictly control for the high speed rail, and it has be specified in rail standard\(^{[7,8,9]}\), such as rail used for 200km/h need control A type inclusion grade ≤ 2.5 however 350km/h need ≤ 2.0, besides the rail steel deoxidation without aluminium while smelting process, and large content of Mn but low S. MnS separation control is benefit for the control of decreasing A type inclusion grade in rail, and improve the rail property, so many researchers carried out work for smelting process\(^{[10,11,12]}\).

Continuous EMS technology control the flow field of molten steel during the continuous process and advance the solidified structure, the same as chemical composition purity and inclusion floating remove, it has been used widespread since the 1990s\(^{[13]}\). EMS relate to the grade of MnS inclusion which segregated at solidus temperature for rail steel. This paper carried out contrast experiment at U75V, and analyze the effects of stirring magnetic intensity on the segregation of MnS at a special position in rail based on the scanning statistic results that tested by Aspex, measures to control was proposed based on the analyzation of testing result and segregation characteristic of MnS.
2. Test method
Comparing experiment was carried out to explore the effects of stirring magnetic intensity on the segregation of MnS, mainly based on the condition such as smelting refining, dioxygen, CC speed, CC temperature and molten steel fluid level stable and consistence. The equipment of CC machine just shows as table 1.

| Projects                              | Parameters                                      |
|---------------------------------------|-------------------------------------------------|
| Manufacturer                          | SVAI                                             |
| Type                                  | Full arc Multipoint straightening                |
| Brand                                 | 6                                               |
| Heat size                             | 280mm×325mm, 280mm×380mm                        |
| Bending radiuses, m                   | 12                                              |
| Machine length, m                     | ~35.60                                          |
| Mold type/length, mm                  | Combined, 850                                    |
| EMS install position, Core length     | Mold low end, 500                               |
| EMS Manufacturer                      | ABB                                             |
| Straightening and withdrawal          | 7                                               |
| Soft compression                      | Equipped                                        |
| CC speed /min·min-1                   | 0.70±0.05 m/min                                 |
| Super heat /°C                        | 17~35                                           |
| Second cooling /L·kg⁻¹                | 0.25                                            |
| Work speed and reduction amount       | (0.70m/min or 0.75m/min)                        |

This paper chooses the reality magnetic intensity as research projects, and measured the different electricity intensity as fig.1. Results shows that magnetic intensity increase at first until over the position where from mold liquid level 500mm, and magnetic intensity in the area where from mold liquid level 500~700mm is the most.

![Figure 1. Intensity curve of reality magnetic field intensity.](image)

Stirring magnetic intensity (Gs) was tested for different electricity at different position from mold liquid level, and the results shows as Fig.2. Magnetic intensity is the most where 600mm from mold liquid level at the same electricity, on the other hand stirring magnetic intensity come to be increase with the increasing of electricity intensity.
Based on the actual measurement amount of magnetic intensity, different stirring magnetic intensity at the position where from mold liquid level 600mm was chosen to carried out comparing test at the same brand, and the intensity are 0Gs, 195Gs, 210Gs and 220Gs, that defined as project1 to project4. The content of [S] % in testing rail steel is kept to be 0.004%. And casting with 0.70m/min, superheat is about 30°C. And the testing billets were rolled to be rail that is 60kg/m.

3. Testing samples test
Taking samples according to the Railway Standards from the rail which rolled from testing billets, and choose the position where below the tread 12.5mm as the testing surface. Samples machined to be metallographical sample and take scanning test by Aspex, to statistics the date information of MnS inclusion. Got the key date like the length size distribution of single MnS inclusion, two dimensional area scale by transformed the testing date unify, then compare the purity and compound state MnS among the different stirring process at last. Another side, length size distribution was statistics and conversed according to the testing area demand from railway standard, that means based on the testing area are 200mm²; and inclusion area scale are conversed to be per mm².

4. Testing results and analyzation

4.1. Effects of stirring magnetic intensity on length size distribution
Effects of M-EMS stirring intensity on the size distribution of MnS inclusion is shown as fig. 3, as the fig. 3(a) shows that the stirring intensity enlarged while the amount of pure state MnS inclusion which single length size belong 10~20μm is decrease evidently; single pure state MnS which length size >50μm is appeared while stirring intensity at No.4 could be found in fig. 3(a) at the same time. Besides pure state MnS inclusion, the size distribution of compound state MnS inclusion is shown as fig. 3(b), it could be found that the size of compound MnS inclusion mainly distribute at 10~20μm, while big size inclusion at 20~50μm is appeared at No.4 stirring intensity which is the strongest, on the other hand the stirring intensity enlarged while the amount of compound state MnS inclusion is increase.
4.2. Effects of stirring magnetic intensity on area proportion of MnS
The effects of M-EMS stirring magnetic intensity on the area proportion (two dimensional) of MnS inclusion is shown as fig. 4, the research condition have been united that the [S]% are 0.004%. fig. 4(a) shows that the total area proportion of pure state MnS is decrease at first stage but increase at the following stage with the M-EMS stirring intensity enlarged, however the total area proportion of compound state MnS is increase at first stage but decrease at the following stage with the M-EMS stirring intensity enlarged. Fig. 4(b) shows that the average area proportion of pure MnS is the minimum while stirring with No.1 stirring intensity, and the average area proportion (two dimensional) is increase at first and then tend to be decrease, the maximum is $0.48 \times 10^{-4}\%$ which is produced from No.2 stirring intensity; and the same trend for the compound MnS inclusion, however the area proportion (two dimensional) of compound state MnS is higher than pure MnS.
Combined figure 3 and figure 4, conclusion could be found that the amount of pure state is far more than compound state MnS inclusion at same stirring intensity, however the single area proportion (two dimensional) of pure state MnS inclusion is lower than compound state, which is caused by the difference of deformation characteristic during the rolling process between pure state and compound state, in other words the hardness nucleus restrain the deformation of MnS which is bundle layer, that lead the compound state MnS inclusion shows as short-wide but long-thin for the pure state MnS inclusion, the typical photographs of pure state and compound state MnS inclusion compared as fig. 5.

**Figure 4.** Effects of M-EMS stirring intensity on two-dimension area ratio of MnS

**Figure 5.** Representative graph of pure and compound state MnS inclusion
Conclusions that MnS inclusion is mainly formed with pure state while the amount of nucleation particle was not change can be reached by analyze the testing results; under the same condition for the content of [S], stirring advance the purity of molten steel and restrain MnS inclusion precipitate during the process of molten steel solidifying, however if the stirring intensity tend to be too strong, the concentration gradient between stirring belt and the extending area would be enlarged, this situation spur the content of [Mn]% and [S]% on greater then push the bigger size pure state MnS inclusion precipitate, and promote the compound state MnS inclusion to be bigger size which was nucleated at the same time, and also increase the nucleate ration, that’s lead the mount of compound state MnS inclusion increase and big size inclusion appeared as result of stirring intensity too strong. Lower the volume ratio of nucleus is more disadvantages for the hold-up of MnS inclusion deform, in other words worse for the control of A type inclusion rating. Generally speaking, big size pure state MnS inclusion is the worst for the control of A type inclusion rating.

Combine with the precipitate thermodynamic analysis, it could be founded that measures to control MnS inclusion precipitate rate under the same rolling process and lower content of [S] contain two aspects: first is to provide more nucleate particles; second advance nucleate and control the compound state MnS inclusion grow up to avoid the volume ratio of nucleus too low, based on the two aspects to formulate 210Gs as the suitable stirring intensity, that would be benefit for the control of MnS inclusion precipitate in rail.

5. Conclusions
(1) State of MnS inclusion in rail mainly precipitate with pure state by the condition that not increase nucleate particles.
(2) Stronger stirring intensity of M-EMS with the same condition of same [S]% bigger size pure state MnS inclusion precipitate more easy; and nucleate ration of compound state MnS inclusion would be increased, precipitate and formed tendency of bigger size compound state MnS inclusion increased too.
(3) Increase the nucleate particles and control M-EMS at 210Gs to be a suitable stirring intensity would be helpful for the control of MnS inclusion precipitate and distribute in rail on the condition of lower content [S] in steel.

6. References
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