Mechanism of spot-like centerline segregation formation in continuous casting

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Centerline segregation in continuous casting has been improved over the years by employing new technologies such as soft reduction in the final stage of solidification and prevention of bulging. The type of the morphology of centerline segregation is divided into two types; band-like segregation which appears only in the case of slab casting and is caused by bulging and spot-like segregation which appears discontinuously in the longitudinal direction both in slab and bloom castings. The mechanism of band-like segregation is well understood and successfully reproduced by mathematical modeling and simulation [1,2]. On the other hand, the mechanism of spot-like segregation formation is not consistently understood well for slab and bloom castings as suggested by the following facts. The formation mechanism of spot–like segregation in bloom casting is explained by the bridging of equiaxed crystals and suction due to solidification shrinkage [3] but spot-like segregation also appears in the slab with columnar structure [4].There are big differences in the size and interval of segregation spots between slab casting and bloom casting [3,4], but there is almost no previous literature that explains the reason for these phenomena. In addition, recent reviews on centerline segregation [1,2] do not mention anything on the formation mechanism of discontinuously located spot-like segregation.

In this paper, the size distribution of segregation spots is analyzed and the new mechanism of discontinuously located spot like segregation formation, which would be valid for both slab and bloom castings, is proposed based on the author's previous study[4] and current knowledge of relevant phenomena. The fact that segregation spots are discontinuously located in the casting direction indicates that solid fraction at the center of slab or bloom shows irregularity in the casting direction. Such irregularity in solidification front easily results in bridging, because the angle between solidification front and center of cast material is very small in the case of steel casting [5]. In addition, V segregates are observed near the surrounding area of bridging part even in the case of the slab with columnar structure and the size of spot-like segregation has close relationship between the numbers of V segregates and is greatly decreased by soft reduction [4]. These facts indicate that solidification front shows irregularity in its shape which causes bridging at the portion where solidification advances, and the most essential and unavoidable cause of spot-like segregation formation is the combination of bridging due to irregularities in the solidification front and suction due to solidification shrinkage, irrespective of the solidification structure. Moreover, it was found that the cumulative probability of the size distribution of segregation spots obeys a power law distribution, as shown in Figure 1. This suggests that the solute-redistribution system in the mushy zone is characterized by fractal structure and self-organized criticality [6]. The former suggests that larger and smaller irregularities are governed by the same mechanism, while the latter suggests that the interaction among dendrites due to solute mixing would be a major factor responsible for the growth of both irregularities and segregation spots. Based on these findings, the

formation mechanism of spot-like segregation is considered as follows. Microscopic irregularities in the spatial arrangement of dendrites in the mushy zone, initially caused by fluctuations in solidification, increase during solidification because of solute mixing among dendrites, resulting in bridging at a certain solidification stage. This enhances the solute enrichment at the portion below the bridging part and the growth of segregation spots progresses in a mutually dependent fashion with the growth of irregularities in the solidification front during the final solidification stage. Various features of spot-like segregation in both slab and bloom castings are consistently explained by this mechanism. The mechanism and process of the formation of various types of centerline segregation are schematically depicted in Figure 2.

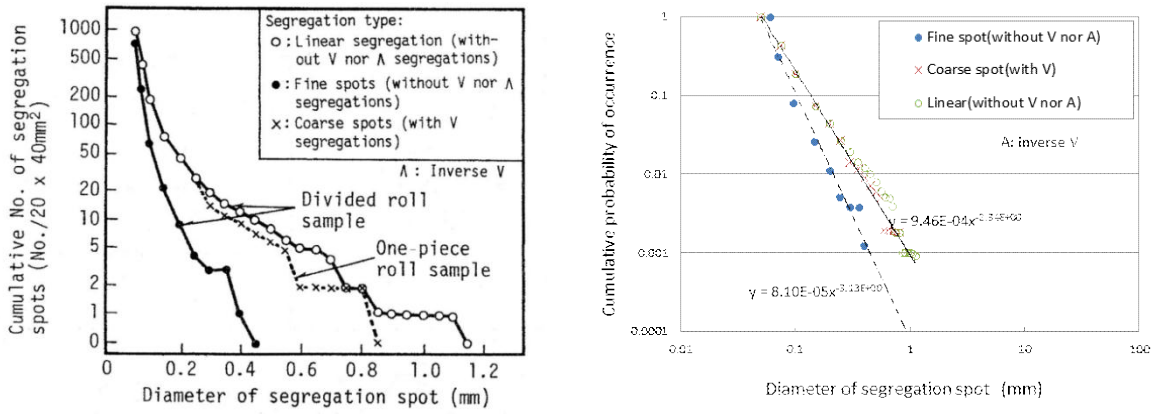

Fig. 1 Distribution of cumulative number (left [4]) and probability (right) of segregation spot diameters.

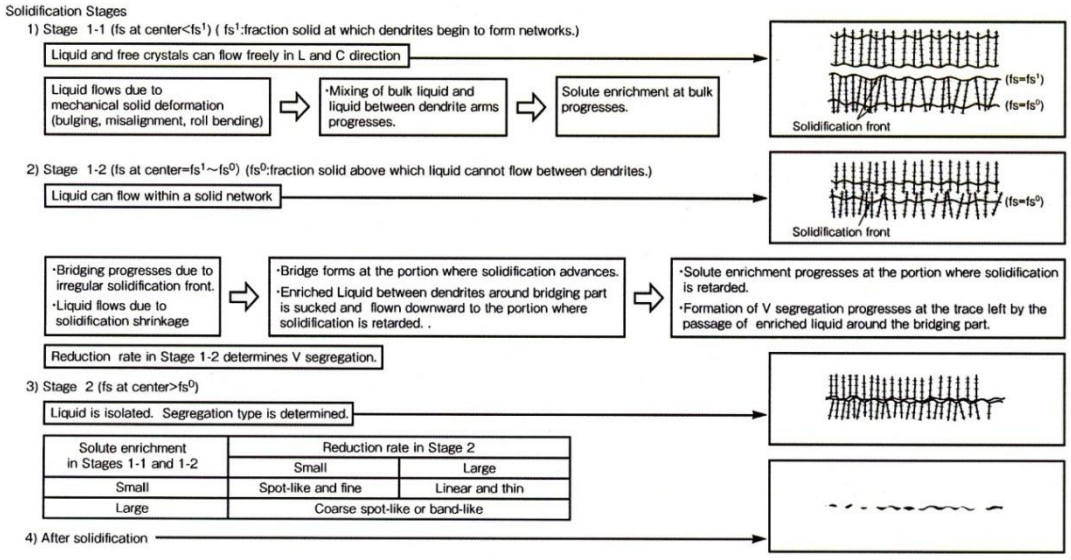

Fig. 2 Mechanism and process of the formation of various types of centerline segregation. Fine spot-like segregation is obtained when solute enrichment in stages 1-1and 1-2 is small due to optimum soft reduction and prevention of bulging.

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