Low oxygen content eliminates channel segregation in cast steels

Keeping the oxygen level low is key to avoiding an important cause of failure in steels, according to a recent article by Dianzhong Li and colleagues in the November 25 online issue of *Nature Communications* (DOI: 10.1038/ncomms6572). Their work at the Shenyang National Laboratory for Materials Science shows that oxygen content of under one-thousandth of a percent reduces or even eliminates a defect known as channel segregation. This is good news for the steel industry with, annually, more than 50 million tons of plates and castings.

A pure metal is rarely used in practical applications; it takes an alloy to meet the exact demands of an engineered product. When a liquid metal cools (or is cast) to a solid, the distribution of elements does not remain uniform, and this segregation can lead to failure of the product. One form of segregation in cast materials, called channel segregation, has a strip-like shape with compositional variation (also known as *freckles*). In large castings, this defect cannot be removed by subsequent thermomechanical processing since diffusion is slow in solids; the component produced typically has to be scrapped.

Li and colleagues looked at a 100-ton steel casting that needed 25 hours to cool at a rate of 5°C/h. Classical theories would expect the occurrence of channel segregation under these conditions, but the researchers didn't see any. They found that their material was comprised of one-thousandth of a percent of oxygen, which suggested a new mechanism based on the oxygen content. Multiscale simulation reveals that oxide-based inclusion prefers to accumulate together to form large inclusions with a diameter of ~5–30 μm. His confirmed experimental results show the range to be 5–50 μm. These aggregates cause channel segregation. The refining technique developed by the researchers lowers the oxygen content and overall reduces the formation of oxides irrespective of the size.

According to Li, "Channel segregation in steels is primarily controlled in the solidification process via rapid cooling, mechanical vibration and electromagnetic stirring. These are not convenient for large components. Our method shifts the emphasis to purification technology for maintaining a low level of total oxygen (about 1×10^{-3} wt%) and jointly limiting the other impurity elements (i.e., S and P)."

Co-author of the study, Yiyi Li, says that the project "is an important step forward in steel casting technology and extends the classical theories of channel segregation. The combined approach of simulation and experiment is providing an effective way to shed light on old metallurgical problems."

According to Merton Flemings, a pioneer of the theories of macrosegregation, "The [researchers] make a convincing case for a driving force not heretofore considered for the interdendritic flow leading to macrosegregation and freckle formation in carbon steels. They are to be congratulated on the excellent work."

Research by Li and colleagues will stimulate new explorations of a widely applicable mechanism for channel segregation. In the meantime, the technology has been demonstrated successfully in large (535-ton) ingots in collaboration with an industrial partner.

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The 100-ton cast steel ingot ($30Cr_2Ni_4Mo$). Channel segregation was eliminated through purifying technology to get low oxygen content. The type of steel shown here is used for the manufacture of low-pressure rotors in nuclear power plants. Credit: Professor Dianzhong Li.

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