Phosphoric irons for concrete reinforcement applications

The study of archaeological Indian irons, both at low magnifications in the optical microscope and at very high magnification in the transmission electron microscope[1], has revealed several important alloy design criteria to produce ductile phosphoric irons. First, precipitating austenite allotriomorphs by a high temperature anneal can restrict P segregation to the grain boundaries. Secondly, phosphorus segregation can be avoided by locating a small amount of carbon/carbide along the grain boundaries. Thirdly, precipitation of phosphide phase in the ferrite matrix, in a manner similar to age-hardening Al alloys, would prevent P segregation to the grain boundaries apart from providing additional strength. Suitable heat treatments and thermomechanical processing can easily achieve the required microstructure as per the alloy design proposed. It is important to undertake detailed studies on microstructural control and the effect of microstructure on the mechanical behaviour in phosphoric irons.

The present communication addresses possible ways by which phosphoric irons can be manufactured and processed on a large scale. As regards the metal extraction stage, the iron produced from the blast furnace would be the primary material for producing phosphoric iron. This ensures that the large productivities that are achieved in the blast furnaces are maintained. The phosphorus impurity from the iron ore remains in the extracted metal because of the reducing conditions maintained in the blast furnace. Therefore, the selection of high phosphorus-containing ores for iron extraction can be envisaged. These high-P ores are deliberately not being mined at present and one beneficial effect that will accrue is that the large reserves of high phosphorus iron ores can be mined for iron extraction. In the next step, the carbon content of the extracted pig iron has to be reduced. Levels down to 0.05% C can be easily achieved in the LD converter without entailing significant additional costs and change of operational parameters. It must be realized that P will also be removed during the decarburization process in the LD converter and this can be easily replenished by the well-established techniques of rephosphorization (which is currently used for producing automotive grade steel). The ingots thus obtained need to be soaked at high temperature for further thermomechanical processing.

In this context, it is important to consider the production of reinforcing bars because a large tonnage of steel produced in a developing country like India is used for reinforcement of concrete in structural applications. The reinforcement bars have to possess the necessary strength, ductility and corrosion resistance. Modern-day reinforcement bars are strengthened by three methods, namely, microalloying with costly elements like Nb, Ti, etc., cold twisting (which used to be popular earlier), and by controlled cooling in the bar mill plus temp-core cooling process. The bar mill plus temp-core cooling process can produce bars in large tonnage with high productivity. In this process, the soaked ingots are first reduced in size to the shape of bars by means of rolling through a set of rolling strands. When the bar comes out of the final rolling strand, it moves through a quenching stand, wherein surface quenching results in martensitic structure in the outer region of the bar. However, the higher temperature existing in the core, heats up the surface, as the bar proceeds away from the quenching stands and tempers the surface martensite. In this way, this process produces a hard and tough surface layer with a ductile interior. This is one of the most popular methods for producing large quantities of reinforcement bar material. The complete bar mill plus temp-core cooling process has been explained here because the phosphoric irons can be processed by the same method utilizing the existing arrangements, with the major difference being the ingot soaking, bar quenching and further cooling arrangements have to be fine-tuned to produce phosphoric iron with a tough surface and a strong interior, by achieving the three design criteria outlined earlier.

There are several advantages of utilizing phosphoric irons for reinforcement applications. The most important, of course, is that there is no need to change the existing iron and steel-making technologies and thermomechanical processing technologies for manufacturing phosphoric iron bars on a large scale. If the presence of P can be tolerated, there will be no need to address dephosphorization of steel and phosphorus reversal phenomenon that occurs in the ladles. The addition of expensive microalloying elements can be avoided because P (either in solid solution or as phosphide precipitates) can produce the necessary strengths in the bars. The final and most important advantage of phosphoric irons is their remarkable corrosion resistance, and the benefits in this regard have been outlined elsewhere[2].

The beneficial effect of P on atmospheric corrosion resistance of iron will also be obtained when P is present in the microstructure as the phosphide Fe_3P. Iron phosphide readily reacts with moisture to liberate phosphorus after decomposition of the phosphide[3]. Once the phosphide is decomposed on simple exposure to moisture, its enrichment in the rust layer to provide protective properties is ensured. Therefore, the relatively low stability of the phosphide with respect to moisture is a blessing in disguise because atmospheric corrosion-resistant passive films can be produced on the surface. Of course, the phosphoric irons will perform similar to mild steel in the case of exposure to complete immersion conditions. The superior corrosion resistance of phosphoric irons obtains only when mild exposure conditions are involved and not for corrosion in complete immersed conditions (like in aqueous solutions and moist soil environments). The environment in reinforced concrete structures is relatively mild and hence phosphoric irons would fare successfully in reinforcement bar applications. Additionally, the phosphoric irons possess adequate atmospheric corrosion resistance, which is especially important during the transportation (and subsequent storage) of reinforcement bars from the manufacturing site to the final application site.

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