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Blister Formation Mechanisms in Hot Rolling

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Abstract : Oxide scale growth is an inevitable byproduct of the high temperature processing of steel. Blister is a phenomenon that occurs due to oxide growth, where high temperatures result in the swelling of surface scale, producing a bubble-like feature. Blisters can subsequently become embedded in the steel substrate during hot rolling in the finishing mill. This rolled in scale defect causes havoc within industry, not only with wear on machinery but loss of customer satisfaction, poor surface finish, loss of material, and profit. Even though blister is a highly prevalent issue, there is still much that is not known or understood. The classic iron oxidation system is a complex multiphase system formed of wustite, magnetite, and hematite, producing multi-layered scales. Each phase will have independent properties such as thermal coefficients, growth rate, and mechanical properties, etc. Furthermore, each additional alloying element will have different affinities for oxygen and different mobilities in the oxide phases so that oxide morphologies are specific to alloy chemistry. Therefore, blister regimes can be unique to each steel grade resulting in a diverse range of formation mechanisms. Laboratory conditions were selected to simulate industrial hot rolling with temperature ranges approximate to the formation of secondary and tertiary scales in the finishing mills. Samples with composition: 0.15Wt% C, 0.1Wt% Si, 0.86Wt% Mn, 0.036Wt% Al, and 0.028Wt% Cr, were oxidised in a thermo-gravimetric analyser (TGA), with an air velocity of 10litresmin-1, at temperaturesof 800°C, 850°C, 900°C, 1000°C, 1100°C, and 1200°C respectively. Samples were held at temperature in an argon atmosphere for 10minutes, then oxidised in air for 600s, 60s, 30s, 15s, and 4s, respectively. Oxide morphology and Blisters were characterised using EBSD, WDX, nanoindentation, FIB, and FEG-SEM imaging. Blister was found to have both a nucleation and growth process. During nucleation, the scale detaches from the substrate and blisters after a very short period, roughly 10s. The steel substrate is then exposed inside of the blister and further oxidised in the reducing atmosphere of the blister, however, the atmosphere within the blister is highly dependent upon the porosity of the blister crown. The blister crown was found to be consistently between 35-40um for all heating regimes, which supports the theory that the blister inflates, and the oxide then subsequently grows underneath. Upon heating, two modes of blistering were identified. In Mode 1 it was ascertained that the stresses produced by oxide growth will increase with increasing oxide thickness. Therefore, in Mode 1 the incubation time for blister formation is shortened by increasing temperature. In Mode 2 increase in temperature will result in oxide with a high ductility and high oxide porosity. The high oxide ductility and/or porosity accommodates for the intrinsic stresses from oxide growth. Thus Mode 2 is the inverse of Mode 1, and incubation time is increased with temperature. A new phenomenon was reported whereby blister formed exclusively through cooling at elevated temperatures above mode 2.

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