Investigating the effect of temperature on the fracture toughness properties of as-cast DP800 steel slabs

O.D. Taiwo[1a], D Farrugia[2], C.M. Davies[1]

[1]Department of Mechanical Engineering, Imperial College London, UK, SW7 2AZ

[2]Tata Steel UK R&D, 9 Sir William Lyons Road, Coventry, UK, CV4 7EZ

[a]odt17@ic.ac.uk

Introduction

Dual Phase (DP) steel has become commonly used in the automotive industry owing to its formability. Continuously cast DP800 steel slabs, however, are susceptible to the phenomenon of clinking and reheat cracking. Clinking is defined as high temperature audible fracture often catastrophic in nature which can occur in DP800 steel slabs after casting [1]. Fracture is shown to occur perpendicular to the direction of casting and propagate through the thickness. This is related to Mode I failure due to stresses in the casting direction. A link can be seen between the occurrence of clinking and thermal stresses that are generated during slab cooling and reheat [1], however, this has not yet been explored in the case of DP800 steel.

Due to inhomogeneous cooling, continuously cast steel slabs exhibit three zones of solidification: an outer chill zone, a columnar zone, and an inner equiaxed zone. While the chill and equiaxed zones are comprised of randomly oriented grains, the columnar zone displays textured grain growth in the direction of the temperature gradient during its cooling (i.e., towards the middle of the slab). Owing to these distinct microstructures, the fracture toughness observed within each zone is expected to differ (with the columnar zone displaying the lowest fracture resistance due to grain orientation aligned in the <100> direction for BCC and FCC steels [2]). Compositional variation and defects also form in continuously cast steel such as centreline segregation and porosity. These serve as stress raisers within the slab and may initiate cracks which eventually lead to clinking.

Moreover, depending on the composition of the DP800 steel, this grade also classifies as a peritectic steel, worsening the effects of hot ductility troughs and casting defects [3,4] as well as increasing propensity of slab bulging. This is due to the volume shrinkage following the peritectic reaction, as well as the peritectic transformation upon cooldown from the δ-ferrite to austenite [5].

Though hot charging has been used as a viable solution to the mitigation of clinking susceptibility in certain steel grades, this still proves costly. A more robust approach to understanding the underlying mechanisms influencing clinking involves investigating the interaction of the complex thermal stresses with an inhomogeneous solidification structure containing compositional defects such as segregation and porosity. This begins with an understanding of as-cast DP800 microstructure and temperature dependent fracture toughness behaviour.

Method

The solidification microstructure of as-cast DP800 steel pre-reheat was examined for casting defects such as centreline segregation and porosity. A block was extracted from the centre of an as-cast DP800 steel slab, as illustrated in Fig. 1. The dimensions of the parent slab and extracted block are also shown in Fig. 1.

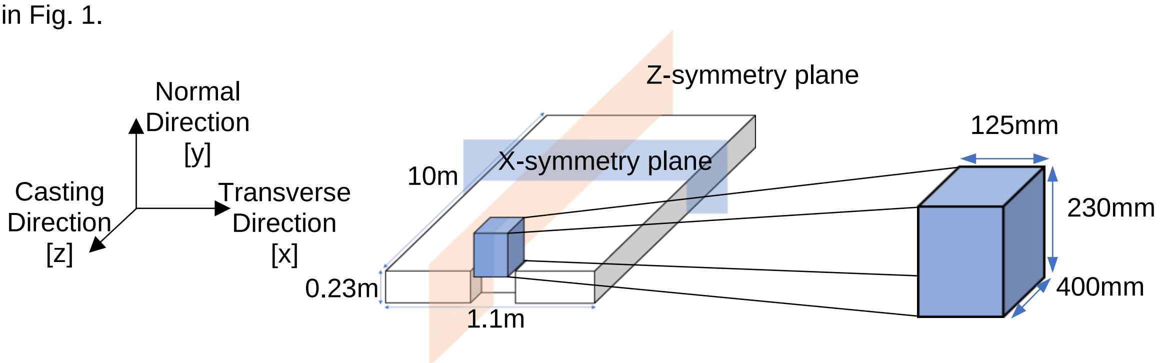

Fig. 1: Showing the position of the extracted block (blue), as well as the dimensions of the slab and block.

The block was further segmented into sub-blocks, with the internal microstructural changes being etched and examined. Defects found were observed using a scanning electron microscope. Charpy V-notched (CVN) impact samples were extracted from each solidification zone and were tested using the ISO-14556 standard. These were orientated with an expected crack propagation plane which was normal to the casting direction. Samples from each solidification zone were tested at a range of temperatures from 20°C to 600°C.

Thermo-mechanical Simulation Results.

A simplified, thermo-mechanical model has been conducted to evaluate the stress distribution and evolution in a slab during cooling and subsequent reheat using ABAQUS. This was done by first evaluating the temperature profile and consequently using the thermal profile to calculate the resulting stresses. The model evaluates the quickest rate of cooling for a slab, as they are often cooled while stacked and not in isolation. Lower cooling rates would reduce the stresses generated in the slab. As illustrated in Fig. 2, the dominant principal stresses in the centre of a slab are in the casting and transverse directions, with the highest magnitude in the casting direction. In line with previously conducted simulations, the stresses peak soon after reheating [6].

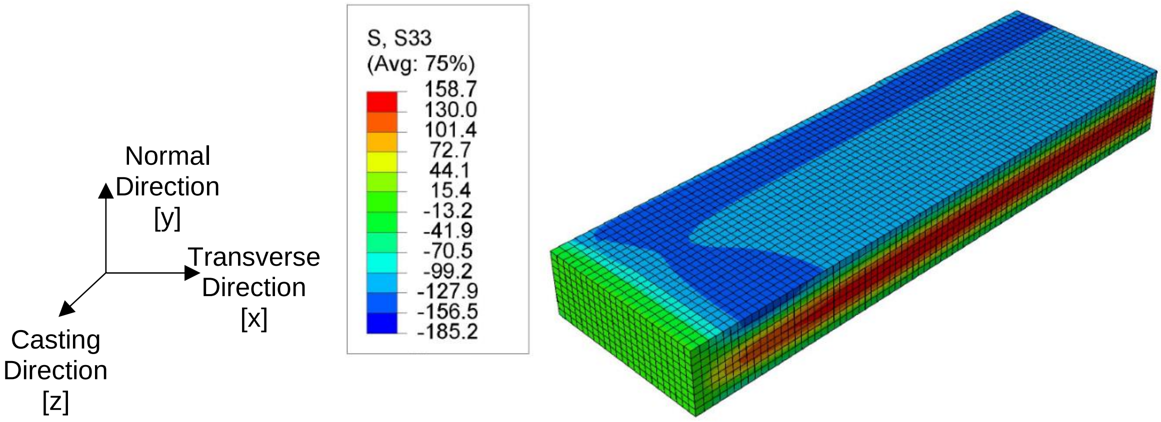

Fig. 2: Showing the peak distribution of stress (in MPa) in the casting direction in a slab (S33). Planes with normal vectors in the transverse and casting direction were used as symmetry planes.

Conclusions

As-cast DP800 steel slabs show susceptibility to clinking during slab reheat, which may result in catastrophic fracture, thus an investigation into its fracture properties is to be conducted. Segregation and porosity are shown by the etching, both worsening towards the centre of the slab, with some defects appearing within the columnar to equiaxed (CET) region. CVN Samples extracted from a DP800 steel as-cast slab will be tested to observe and compare the appearance of the ductile-to-brittle transition for each region. These tests were conducted between 20°C to 600°C and show a transition temperature lower than previously calculated values for electrical steel [2]. Further tests on DP800 post-reheat are to be conducted to provide a comparison with current results.

References

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