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N. Wrigley, G. Jolley, J. Butler. Brittle fracture characteristics of a 50 mm boron containing HSLA steel. Journal de Physique IV Proceedings, 1993, 03 (C7), pp.C7-93-C7-95. 10.1051/jp4:1993711 . jpa-00251727

HAL Id: jpa-00251727

<https://hal.science/jpa-00251727>

Submitted on 1 Jan 1993

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Brittle fracture characteristics of a 50 mm boron containing HSLA steel

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Previous work on a boron containing HSLA steel has shown a variation in the impact fracture transition temperature through the thickness of a 50 mm plate. The inferior properties of the surface regions were attributed to cooling rate effects. This paper describes an extensive metallographic study which shows that the effects can be related to microstructural variations. Surface regions are shown to contain significant amounts of tempered autotempered martensite while central regions were mainly bainitic. Transmission electron microscope studies revealed the presence of dislocation substructures in the bainitic regions which were not found in areas of autotempered martensite. Careful studies of the fracture path in the transition region showed that the large autotempered martensite laths facilitated brittle crack propagation. The mechanics of formation of autotempered martensite in these steels and its significance are discussed.

INTRODUCTION

A new high strength low alloy (HSLA) steel, RQT 701 (New) has been developed as a possible replacement for the Q(N) range of steels at present used in the U.K. for submarine hull construction. RQT 701 (New) is a low nickel, boron containing, quenched and tempered steel and is less expensive than the Q(N) steels because of its lower nickel content; the hardenability being maintained by the boron addition. A comparison of the composition of the material with Q2(N) is given in a previous publication^[1]. Preliminary testing of RQT 701 in 50 mm plate revealed a marked difference in the through thickness properties^[1]. The naval requirement for impact properties is a charpy level of above 80 Joules at -85°C . It was found that while central regions of 50 mm plate met this specification, the surface regions failed. Fig. 1 compares the mid thickness and surface regions of RQT 701 (New) with Q2(N) demonstrating this effect. Fig. 2, taken from the same publication,^[1] shows the effect of re-heat treating small samples of RQT 701. In this case, the variation across the thickness had been eliminated but both regions were inferior to Q2(N).

Fig. 1

Fig. 2

It was suggested, therefore, that impact variations in the steel were due to cooling rate effects and this was supported by metallographic evidence showing that microstructural variations occurred across the thickness of 50 mm RQT 701 plate. This paper produces further supportive microstructural evidence to explain the fracture variations.

MICROSTRUCTURAL INVESTIGATION

The previous paper had shown that surface regions of the RQT 701 50 mm plate contained large tempered autotempered martensite laths with a fine tempered martensite structure. Central regions were shown to contain fine tempered martensite and upper and lower bainite. This work was carried out on a scanning electron microscope and it was felt that transmission electron microscopy was required to confirm the interpretation.

Extraction replicas and thin foils were prepared from samples across the plate thickness. It was found that the surface regions contained much greater amounts of large tempered autotempered martensite laths with fine precipitates of carbide. Some lower bainite regions and fine tempered martensite were also observed. The central region of the plate contained smaller amounts of the autotempered laths and exhibited mainly bainitic structures. Figs. 3 and 4 demonstrate this effect.

Fig. 3 Sub surface x8000

Fig. 4 Sub surface x8000

The thin foil work revealed the dislocation arrangement within the microstructures. The areas of fine martensite and bainite revealed sub grain structures while the large laths of tempered auto tempered martensite were free from such effects. Fig. 5 demonstrates these effects in a sub surface region.

Fig. 5 Sub surface x20,000

Fig. 6

To investigate the effect of microstructure on the fracture behaviour, fracture sections were prepared from charpy samples in the transition range. The surfaces were nickel plated to give edge protection. The results of the study showed that the large autotempered lath martensite was the phase which behaved in a brittle manner at the highest temperature. Fig. 6 is taken from a sub surface specimen and the fracture path runs from left to right. The greater ductility of the bainitic regions is apparent from this photograph.

DISCUSSION

The evidence produced in this paper confirm that the fracture variations across the thickness of RQT 701 plate are a result of microstructural differences and that increasing the bainite content results in improved toughness. Tometa^[2], amongst others, has reported on the benefits of mixed bainite and martensite structures. It has been shown that increasing amounts of tempered autotempered martensite laths leads to brittle behaviour. The metallographic examination suggests that this is due, in part, to a lack of dislocation substructure which would encourage crack branching and divert the path of brittle cracks.

The mechanism of formation of the large autotempered laths requires further study. It appears from metallographic examination that the laths nucleate at austenite grain boundaries and grow inwards perpendicularly. The growth terminates with a change in mechanism to upper bainite. The laths are quite large, i.e. 2-4 μ m wide and several μ m long. They contain a fine carbide precipitate and revealed evidence of internal twins which extend only partially along the laths. Work by Bhadeshia^[3] suggests that these may be accommodation defects. Future publications will deal in more detail with the nature and mechanism of formation of this phase with particular reference to the role of the boron addition to the steel.

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