# BRITTLE FRACTURE MECHANISMS OF THREE MODEL LOW ALLOY STEELS CHEMICALLY REPRESENTATIVE OF A MACROSEGREGATED FORGING

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**Abstract**

The influence of the chemical composition on the brittle fracture behaviour of pressure vessel steels was investigated. Two model materials with chemical compositions simulating zones of moderate and severe positive macrosegregation were characterized and compared with the non-segregated material. Fractographic analysis suggests that brittle fracture mechanisms depend on the chemical composition through the induced microstructure.

## 1. Introduction

In the nuclear industry, very large components such as the reactor pressure vessel are forged from heavy ingots. These ingots generally feature the so-called zones of positive macrosegregation, where the content of carbon and other alloying elements is slightly superior to the nominal composition of the ingot. Generally, these zones cannot be completely eliminated and limited segregations (%Cmax = 0.22%wt) can still be present in the final component. In some rare cases where the level of macrosegregation could be larger than expected, extensive destructive material characterization is mandatory to check that the brittle fracture toughness is high enough to ensure the structural integrity of the component [1-3]. The present paper thus investigates the influence of the chemical composition on the brittle fracture mechanisms of bainitic pressure vessel steels through the characterization of three model materials chemically representative of a macrosegregated forging.

## 2. Materials

Three materials obtained from laboratory castings have been investigated: a material with a chemical composition similar to the RCC-M code material type 18MND5 bainitic pressure vessel steel (close to ASME A508 Gr3 Cl2) —i.e. non-segregated material—and two materials with chemical compositions simulating zones of moderate and severe positive macrosegregation. For all materials, an homogenization heat treatment was carried out before forging operations to reduce the influence of the microsegregation observed in previous investigations [4]. Note that this homogenization is not part of the usual heat treatment procedure of industrial components and has been carried out in an attempt to isolate the effects of the bulk chemical composition in the present analyses. Forging operations were followed by a standard heat treatment procedure simulating quenching, tempering and post-weld heat treatments. Surprisingly, for these conditions, fracture toughness of the homogenized model materials appears to be improved when increasing the carbon and alloy elements content. Fractographic analyses of both V-notched Charpy and Compact-Tension specimens were carried out to investigate the influence of the chemical composition on the brittle fracture mechanisms and microstructure.

## 3. Results

It was observed that the brittle fracture mechanism depends on the macrosegregation level. For the non-segregated material and for an intermediate level of macrosegregation, transgranular cleavage was the dominant mechanism (Fig. 1). The microstructural features at the origin of cleavage fracture in both cases were often identified by EDX as manganese sulphides (MnS), as indicated in Fig. 1. For the highest macrosegregation level, a mix of transgranular cleavage and intergranular fracture was observed (Fig. 2). It was not possible to identify which microstructural feature was at the origin of brittle fracture since the initiation site could not be precisely determined.

It was also observed that the morphology of cleavage facets depends on the macrosegregation level. Relatively large cleavage facets were observed for the non-segregated material and for a moderate macrosegregation level. Conversely, smaller cleavage facets, similar to those observed in martensitic zones in a previous investigation [5], were prevalent for the highest macrosegregation level. This result suggests that the microstructure for the highest level of macrosegregation might be martensitic. This hypothesis is investigated thanks to metallographic and EBSD characterizations, together with the modelling of fracture toughness of the three materials based on a local approach model [4].

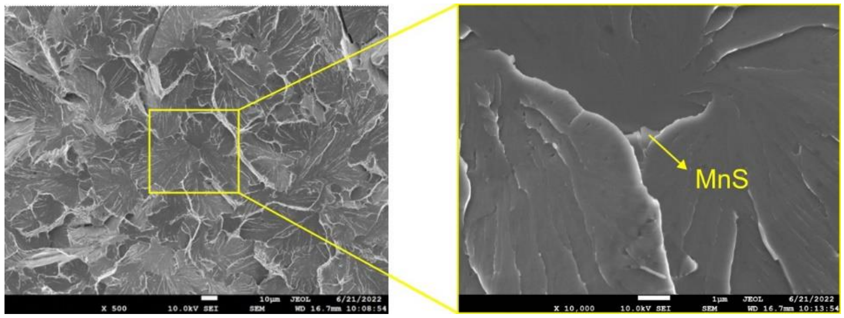


Figure 1 – Typical fracture surface observed for non-segregated and moderately segregated materials. Initiation site identified as MnS.

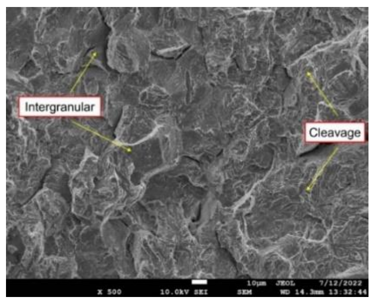


Figure 2 – Brittle fracture mechanisms observed for the highest level of macrosegregation.

## 4. Conclusions

For the non-segregated material and for an intermediate level of macrosegregation, cleavage fracture was the dominant mechanism of brittle fracture, often originating from small (< 5µm) manganese sulphides (MnS). For a higher level of macrosegregation, both cleavage and intergranular fracture were present, with no clear microstructural feature at the origin of the failure. The morphology of cleavage facets suggests that a martensitic microstructure may be present at the highest level of macrosegregation, in contrast with the usual bainitic microstructure. The improvement of the fracture toughness for the most segregated material is probably induced by this modification of the microstructure throughout the material which was made possible by the homogenization treatment.

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