Advanced Imaging of Ductile Fracture Mechanisms Using X-ray Computed Tomography

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INTRODUCTION AND AIMS

Ductile fracture, which takes place after a large amount of plastic deformation, is a complicated phenomenon and significantly affected by several factors, such as stress triaxiality, working temperature, strain path, strain rate and the geometry of the working piece.[1] Ductile failure in metals or metallic alloys is multiple stages of void nucleation from inclusions or second phase particles, and growth and coalescence of these voids with increasing strain.[2] This sequence of ductile failure mechanisms can be seen in Figure 1. The aims of this research are to determine distinct behaviour of voids nucleated from inclusions and second phase particles and their effects on ductile fracture initiation.

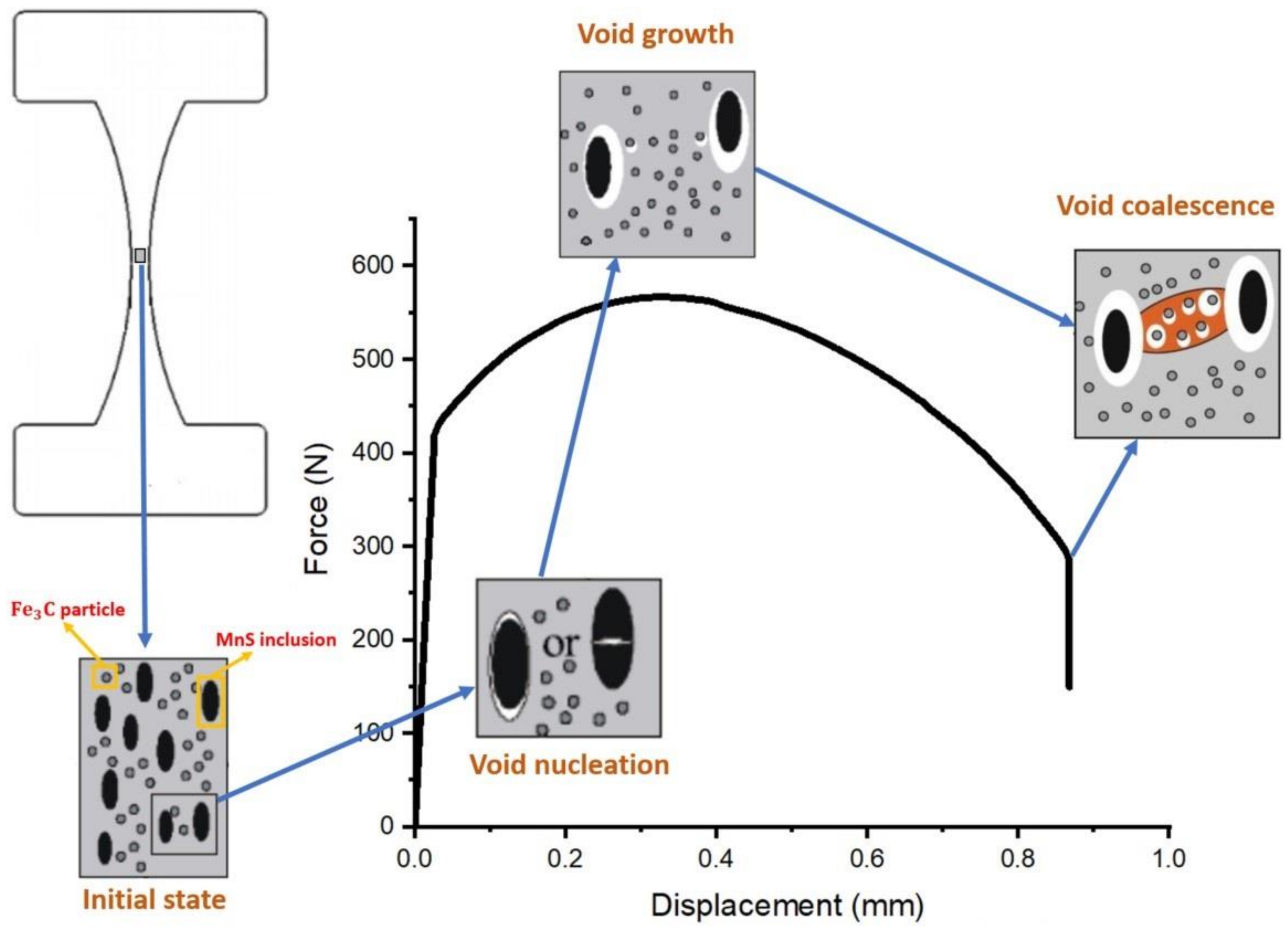

Fig. 1 Mechanisms of ductile fracture for metallic materials.

METHODOLOGY

The SA508 Grade 3 steel has been selected in this study due to its satisfying mechanical properties for nuclear power reactor vessels applications. The tested sample was electro-discharge machined into a smooth sided test-piece which is shown in Figure 2. The chemical composition of the steel was determined by Energy-dispersive X-ray spectroscopy (EDX) in terms of wt %, and it can be seen in Table 1.

Table 1 Chemical composition in wt % of the sample

C	Mn	Si	Ni	Mo	Al	Cr	Cu
0.2	1.48	0.31	1	0.6	0.02	0.25	0.11

High frame rate X-ray tomography experiments were conducted at the European Synchrotron Radiation Facility (ESRF) on beamline ID15A. During tensile loading, filtered polychromatic X-rays with a mean energy of about 50 keV to obtain the high photon flux required to collect fast acquisition measurements. The low energy of the X-ray spectrum has been filtered from the given X-ray beam by an approximately 1 mm thick silicon so that the signal-to-noise ratio (SNR) is enhanced.

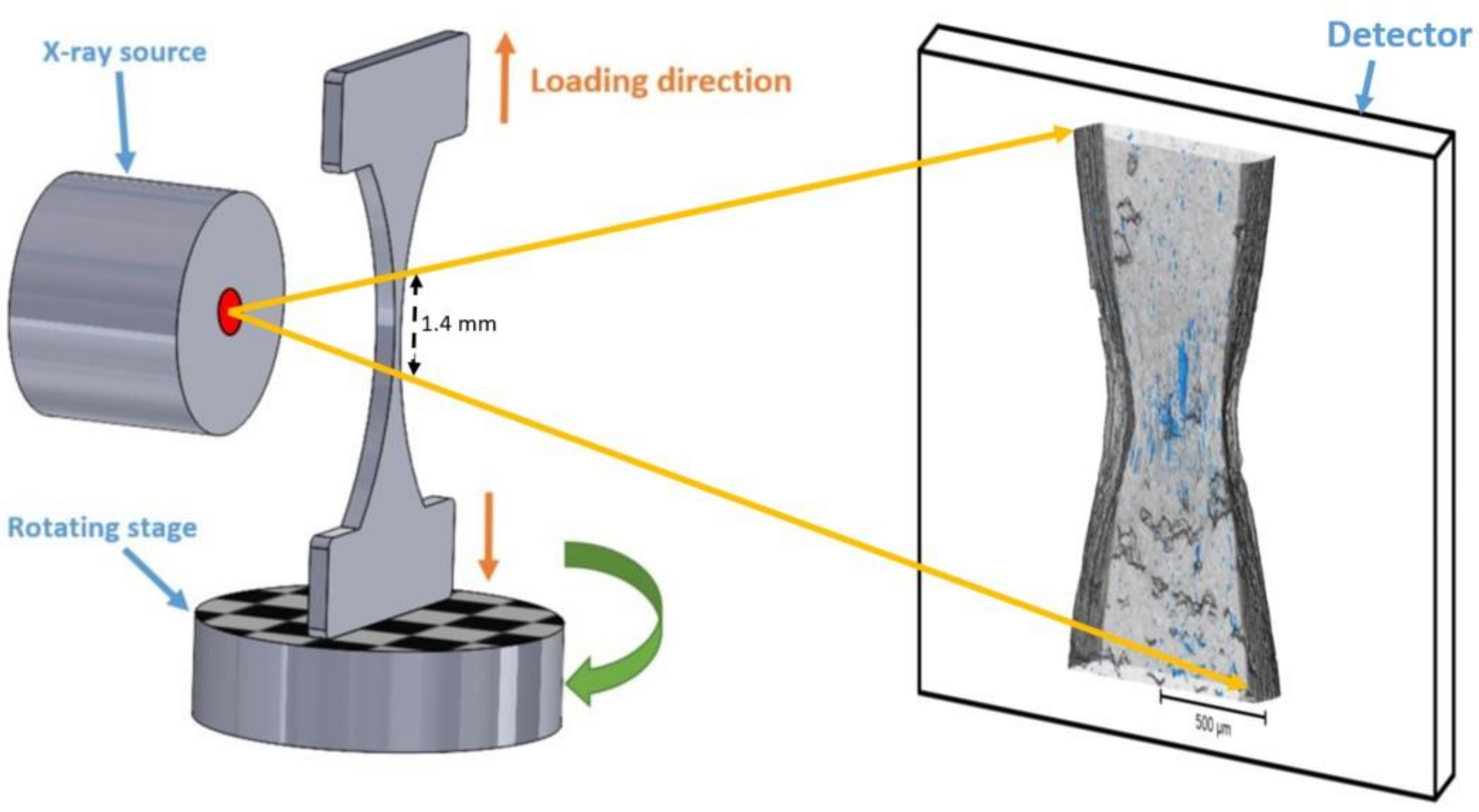

Fig. 2 High frame rate X-ray CT experimental set up.

RESULTS

Ductile materials show typical cup-cone fracture surface shape after failure. This typical fracture surface can be seen in Figure 3a and 3b. Yellow arrows indicate large dimples nucleated from MnS inclusions in Figure 3b. SEM images of longitudinal section of the sample show that MnS nucleated voids homogeneously along the sample. Conversely, cementite particles nucleated voids only in the region close to the fracture surface where the highest stress triaxiality is built.

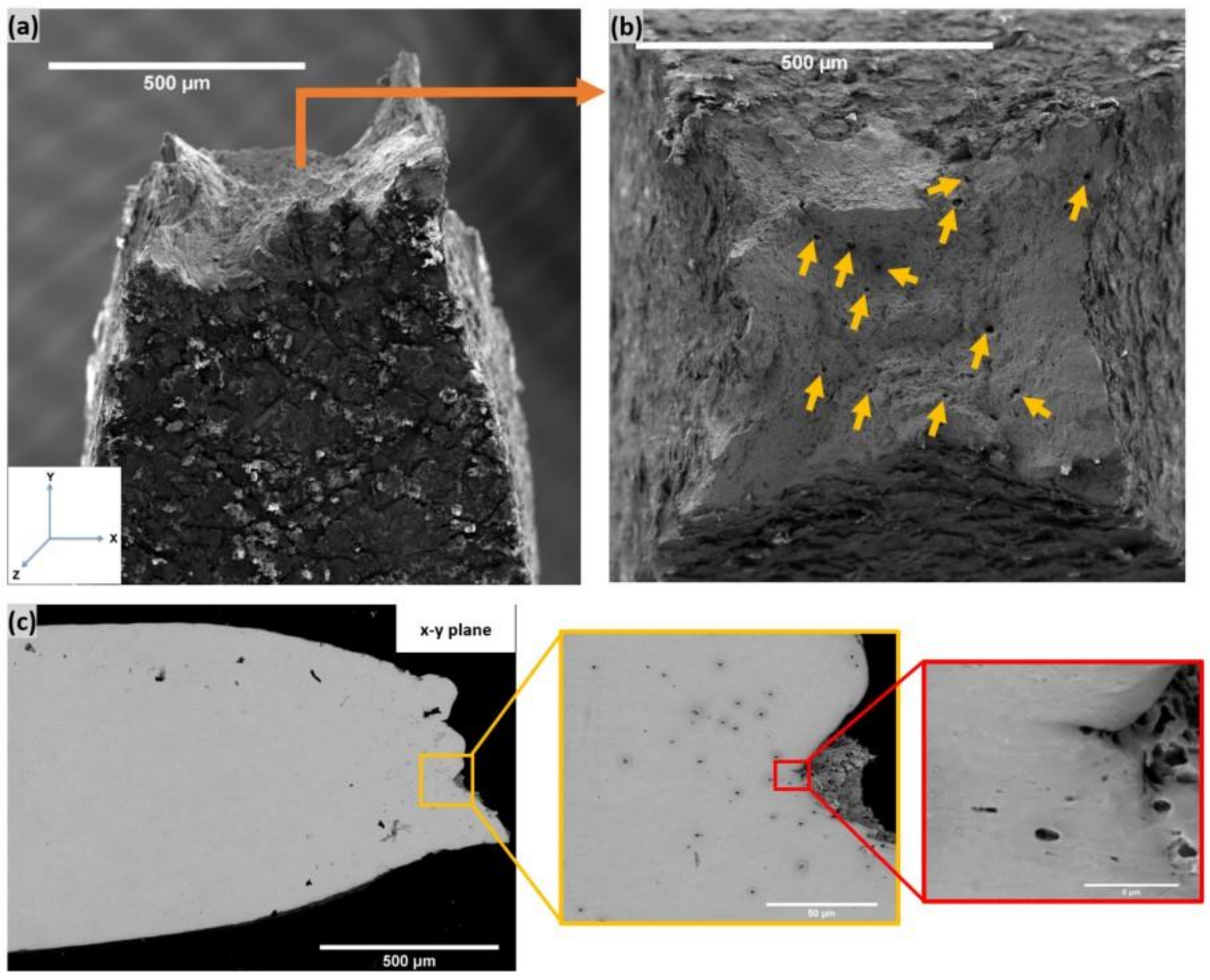

Fig. 3 (a) and (b) Fractagtography of the fractured sample, (c) SEM images of fractured sample along the loading axis.

It was found that the voids nucleated from inclusion have no role on fracture initiation although their volume fraction is greater than the voids nucleated from cementite particles as shown in Figure 4d. Figure 4 a, b and c show the fracture initiation stages by the coalescence of small voids which are nucleated from cementite particles.

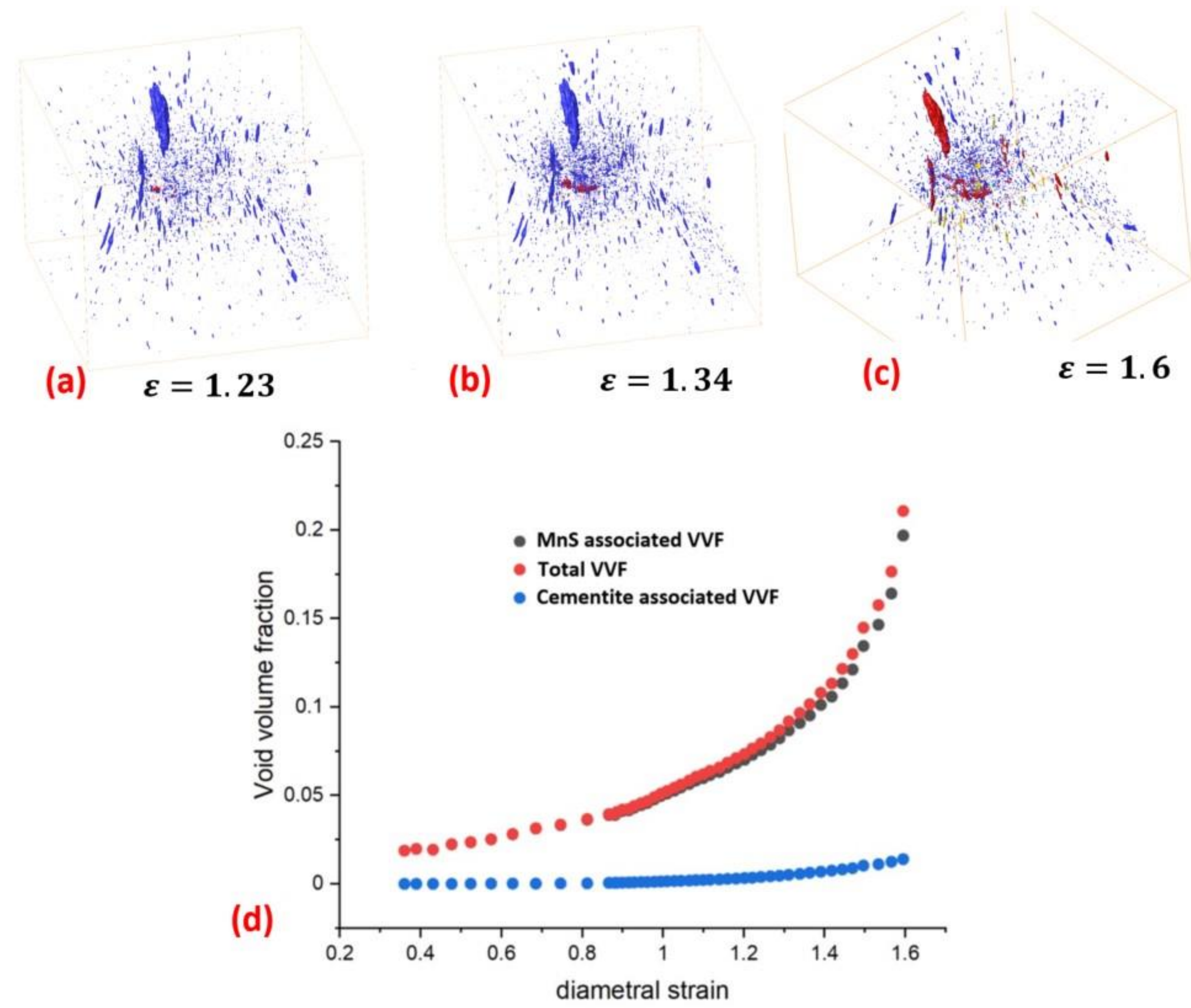

Fig. 4 (a), (b) and (c) Stages of fracture initiation, respectively; (d) total, MnS associated and cementite associated VVF.

CONCLUSION

- Results revealed that MnS inclusions have zero interfacial strength and nucleated voids as soon as the sample was loaded.
- Cementite particles require high stress triaxiality and larger strain to nucleate voids. Therefore, they nucleated cavities only at the centre of necked region.
- Large inclusions have no or little role on initiating ductile fracture. In all cases, fracture was initiated by small spherical cavities nucleated from strongly bonded cementite particles.

References

[1] Pineau, A., Benzerga, A.A. and Pardoen, T. (2016a), "Failure of metals I: Brittle and ductile fracture", *Acta Materialia*, Elsevier Ltd, Vol. 107, pp. 424–483.
[2] Anderson, T. (2005), *Fracture Mechanics: Fundamentals and Applications*, CRC press.

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