Microstructure-based model for the thermo-mechanical behaviour of cast irons

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Introduction

Thermo-mechanical fatigue (TMF) arises as a consequence of thermal related stresses that develop due to thermo-mechanical cyclic loading. In truck engines, the start up-shut down thermal cycling produces valve bridge cracking, resulting in cylinder head TMF failure (Fig. 1).

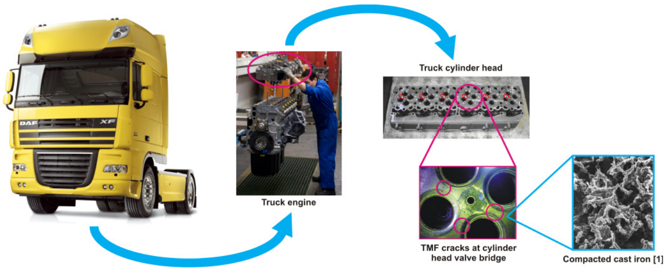

Figure 1: TMF cracks at valve bridges.

Modelling approach

A lamellar cast iron microstructure-based model that includes all relevant microstructural features (matrix/graphite phases volume fraction and continuity, direction dependency of the phases mechanical and physical properties, phases thermal expansion and elastic mismatch) has been developed (Fig. 2).

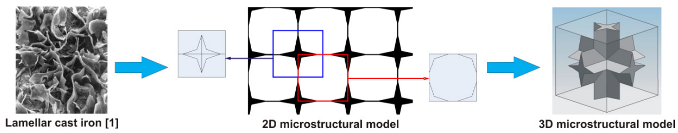

Figure 2: Lamellar cast iron microstructure-based model.

Thermal expansion

When subjected to a temperature change, the phases thermal expansion and elastic mismatch lead to a strain mismatch. Theoretical models yield good estimates for the overall thermal expansion coefficient (CTE) of composites with isotropic phases, but they are inaccurate when anisotropy is present in one of the phases (graphite), Figure 3.

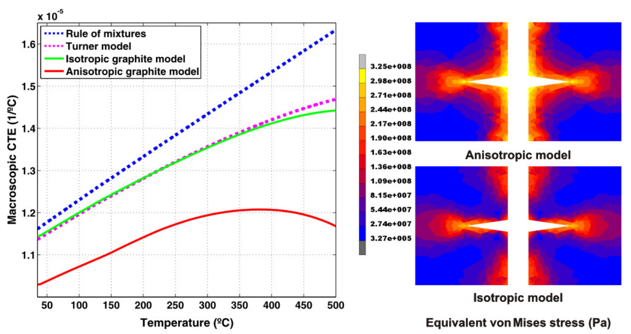

Figure 3: Macroscopic CTE and corresponding local response of lamellar cast iron.

Processing history

When the stress free temperature is assumed to be the processing temperature, cooling down to room temperature produces residual stresses in the microstructure that will lead to a higher macroscopic CTE than if no processing step is considered (Fig. 4).

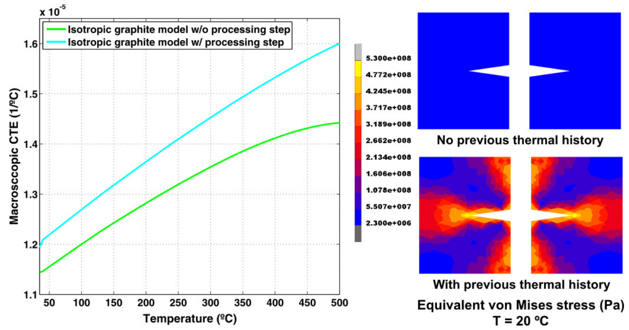

Figure 4: Macroscopic CTE and residual stresses; with and without processing step.

Thermal cycling

Thermal cycling leads to plastic strain accumulation in the matrix over the cycles. The extent of plastic strain accumulation and the rate at which it approaches the saturation level is strongly related to the matrix hardening behaviour (Fig. 5).

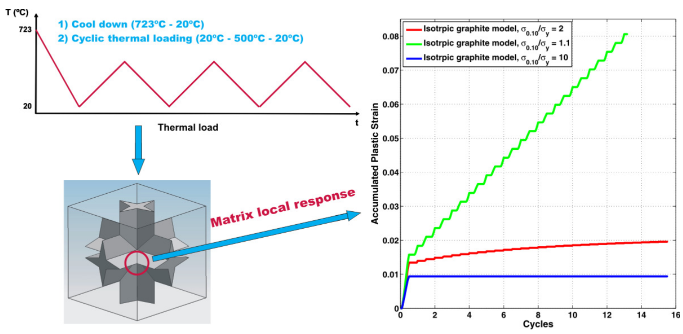

Figure 5: Matrix plastic strain accumulation during thermal cycling for different matrix hardening rates.

Conclusions

A microstructure-based model has been developed that provides insight into the relation between the microstructure and the thermo-mechanical response of lamellar cast iron. This model sets the foundations for the development of a compacted cast iron model that will allow TMF life prediction of truck engine cylinder heads.

References

1. Sjögren, T. (2005), PhD Thesis, Jönköping University, Sweden.