Microstructure-based material model for thermo-mechanical fatigue of cylinder heads

Mechanics of Materials

Technische Universiteit Eindhoven University of Technology

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Introduction

Thermo-mechanical fatigue (TMF) arises as a consequence of thermal related stresses that developed due to thermo-mechanical cycling loading.

- Engine start-stop cycle results in large temperature variations.
- The constrained condition found in cylinder heads, produces compressive and tensile stresses.
- Continuous thermal cycling produce valve bridge cracking, resulting in cylinder TMF failure (Figure 1).

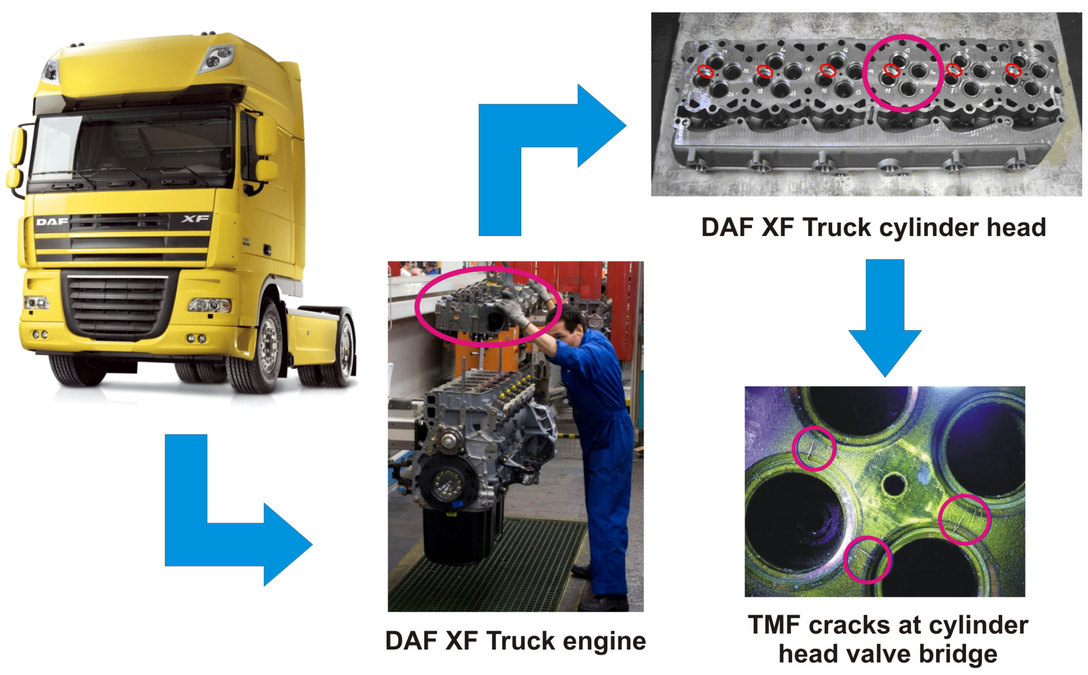

Figure 1: TMF cracks at valve bridges (Courtesy of DAF Trucks N.V.).

Cast iron heterogeneous microstructure (ferrite/pearlite matrix & graphite inclusions, Figure 2), makes prediction of its response at the macro level very complex.

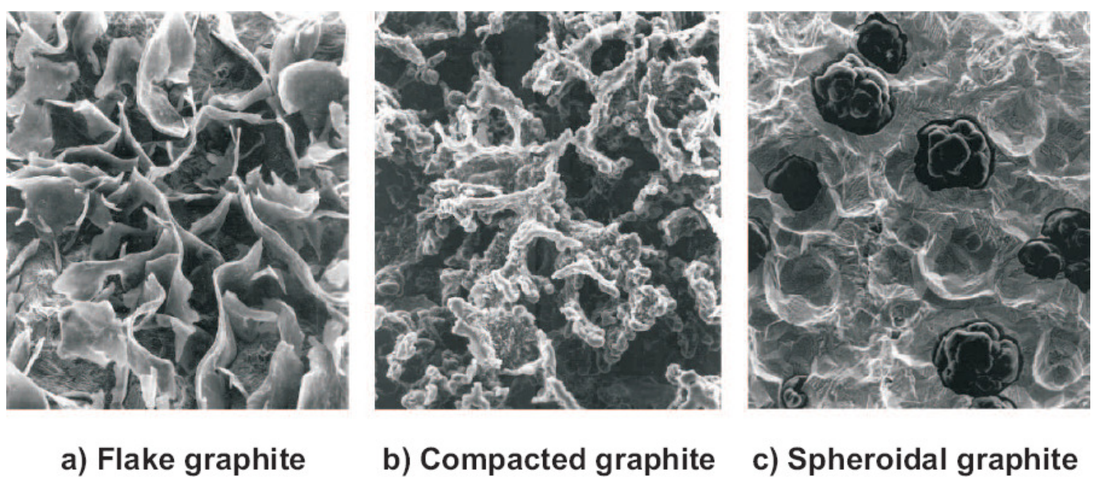

Figure 2: Graphite morphologies found in cast irons [1].

Aim of the project Develop a microstructure-based model for TMF life prediction that considers the different microstructural phases, their interaction and impact on TMF response.

Modelling approach

The basic phenomena to include in the model are:

- 3D Representative Volume Element (RVE) since the microstructure is inherently three-dimensional.
- Microcrack initiation & propagation through the graphite-matrix interface.
- Graphite anisotropy of mechanical & thermal properties.
- Microstructural evolution: oxidation.
- Creep & stress relaxation.
- Thermo-mechanical cycling.

Example Figure 3 shows a microstructure-based material model for nodular cast iron [2].

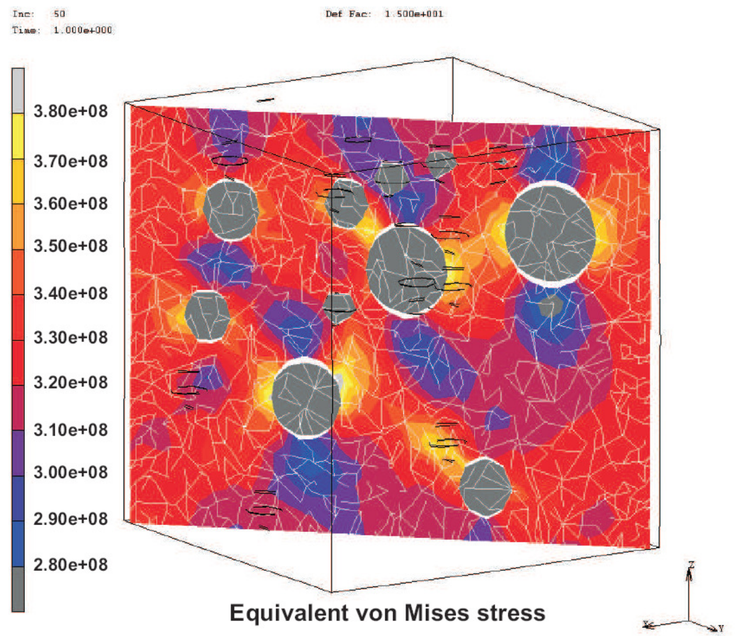

Figure 3: Microstructure-based material model of nodular cast iron under static tensile loading (vertical direction) [2].

Future work

- Improvement of existing cast iron model [2], by including graphite anisotropy and the different matrix phases (pearlite & ferrite).
- Development of cast iron microstructure-based model for thermo-mechanical loading conditions, including microstructural evolution.
- Development of cast iron microstructure-based model for TMF life prediction, where the influence of damage evolution at the micro level is incorporated at the macro level.

References

1. Sjögren, T. (2005), PhD Thesis, Jönköping University, Sweden.
2. van der Oord, G.A.H. (2009), Master Thesis, Eindhoven University of Technology, The Netherlands.