1. Thesis: Damage mechanisms during loading of ceramic composites: Classification of AE signals via machine learning

1.1 Supervisors

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1.2 Abstract

The main objective of the thesis is the classification and diagnostocs of damages in ceramic matrix composites by using acoustic emission (AE) signals and machine learning (ML). Unsupervised clustering by Self-organizing Maps (Kohonen SOMs) shoudl be used primarily to perform a classification of different damage classes automatically. Secondary, supervised learning should be used to classify the AE signals, based on damage classifications retrieved from the unsupervised clustering. The main tasks to be performed is feture selction and the application of standard ML algorithms and models for damage classification.

There are three basic tasks (that can be split into multiple theses): (1) Feature selection (2) Unsupervised clustering to get a damage-AE classification grouping (3) Supervised learning of AE signals to damage classification mapping.

1.3 Description

1.3.1 Damage Assessment and Damage Diagnostics in Ceramic matrix composites

Ceramic matrix composites (CMC) have been developed to improve the low damage tolerance of ceramic materials. These fiber-reinforced ceramics show considerably high fracture toughness, along other properties like high hardness and thermal and chemical resistance. The high fracture toughness and, consequently, damage tolerance of these composites is normally achieved with the use of either porous matrices or fiber coatings. This allows for several crack deflection mechanisms to take place before fiber failure, such as: matrix microcracking, fiber debonding and fiber pull-out. As a result, CMCs show a quasi-plastic behavior when mechanically loaded.

Even though CMCs show enough maturity to be present in several industrial applications, crack propagation/deflection during loading of CMCs is still not fully understood, which is pivotal for the further development of these materials. Different models relating crack deflection with the fracture energy ratio of interface and fiber and the difference between the elastic properties of fiber and matrix can be found in the literature. However, most of them lack of support from experimental data. In addition, it is still unclear how crack propagation happens exactly under loading. Therefore, the objective of this work is to analyze the damage development during loading with in-situ acoustic emission (AE) monitoring.

AE is a useful tool during mechanical tests since the measured AE signals can be related to different mechanical responses and damage mechanisms of the tested material. One of the main challenges of this technique is to relate the measured AE data to their respective damage mechanisms. For that, different evaluation methods can be found in the literature; the most common being related to supervised or unsupervised classification of the AE signals. On supervised clustering, the data to be classified is compared to a training dataset containing already labeled signals. In other words, this method requires a previous knowledge of the features of each possible group of AE signals, which may not be valid for different composites or types of mechanical loading. On the other hand, unsupervised classification can be considered a more general approach, in which AE signals are grouped depending on their features and, later, each group is related to a different mechanism. The main problem of this approach is to identify each cluster and the relation with the correspondent mechanism. In both cases, the choice of the correct features used for classification is also a challenge. Hence, this projects aims on developing a clustering method via machine learning, which can be used to classify AE signals measured during different mechanical loadings of composites. To this end, previously measured data from quasi-static tensile tests and fatigue tests on different types of CMCs will be used in the analyses.

1.3.2 AI Methods

Different standard ML methods should be selected, applied to AE data or derived feature vectors, and evaluated for robust and expressive damage clustering using AE signals:

- Feature selection
  - Identification of significant features of the AE signals
  - Selection and derivation of appropriate feature variables (feature vectors) from the AE signals
- Unsupervised Clustering using Kohonen Self-organizing Maps (SOMs) [11]
  - Using pre-processed time-resolved AE signal data
  - Using feature vectors from AE signals
- Supervised categorical classification
  - Using decision trees and ANN with AE feature vectors
  - using the ouput of the SOM clustering (auto labelling)
- Hybrid model combining the above unsupervised clusteruig with supervised categorisation

1.3.3 Skills

- Basic programming skills are required. The ML framework used in the thesis is programmed in JavaScript and JS is the primary programming language.
- Basic data processing knowledge
- Basic knowledge of materials science

1.4 References

Suggested bibliographies:

[1] W. Krenkel. Ceramic matrix composites: fiber reinforced ceramics and their applications. Wiley-VCH, 2008.

[2] K. Tushtev, R. S. M. Almeida. “Oxide/oxide CMCs – Porous matrix composite systems; Composites with interface coatings”, pp. 130-157 in Comprehensive Composite Materials II, P. W. R. Beaumont, C. H. Zweben (Eds.), vol. 5. Elsevier, 2018.

[3] F. W. Zok. “Developments in oxide fiber composites”. Journal of the American Ceramic Society, vol. 89 (11), pp. 3309-3324, 2006.

[4] M.-Y. He, J. W. Hutchinson. “Crack deflection at an interface between dissimilar elastic materials”. International journal of solids and structures, vol. 25 (9), pp. 1053-1067, 1989.

[5] B. K. Ahn, W. A. Curtin, T. A. Parthasarathy, R. E. Dutton. “Criteria for crack deflection/penetration criteria for fiber-reinforced ceramic matrix composites”. Composites Science and Technology, vol. 58 (11), pp. 1775-1784, 1998.

[6] N. Godin, P. Reynaud. Acoustic emission and durability of composite materials. John Wiley & Sons, 2018.

[7] R. S. M. Almeida, Y. Li, B. Besser, P. Xiao, W. Zhou, A. Brückner, N. Langhof, K. Tushtev, W. Krenkel, K. Rezwan. “Damage analysis of 2.5D C/C-SiC composites subjected to fatigue loadings”. Journal of the European Ceramic Society, vol. 39 (7), pp. 2244-2250, 2019.

[8] G. N. Morscher, Z. Han. “Damage Determination in Ceramic Composites Subject to Tensile Fatigue Using Acoustic Emission”. Materials, vol. 11 (12), pp. 2477, 2018.

[9] N. Godin, P. Reynaud, G. Fantozzi. “Challenges and Limitations in the Identification of Acoustic Emission Signature of Damage Mechanisms in Composites Materials”. Applied Sciences, vol. 8 (8), pp. 1267, 2018.

[10] S. Momon, N. Godin, P. Reynaud, M. R’Mili, G. Fantozzi. “Unsupervised and supervised classification of AE data collected during fatigue test on CMC at high temperature”. Composites Part A: Applied Science and Manufacturing, vol. 43 (2), pp. 254-260, 2012.

[11] V. Emamian, M. Kaveh and A. H. Tewfik, "Robust clustering of acoustic emission signals using the Kohonen network," 2000 IEEE International Conference on Acoustics, Speech, and Signal Processing. Proceedings (Cat. No.00CH37100), Istanbul, Turkey, 2000, pp. 3891-3894 vol.6, doi: 10.1109/ICASSP.2000.860253.