Contents

ACKNOWLEDGEMENTS vii

CHAPTER 1. INTRODUCTION ON VERY HIGH CYCLE FATIGUE 1

1.1. Fatigue limit, endurance limit and fatigue strength 1
1.2. Absence of an asymptote on the SN curve 5
1.3. Initiation and propagation 6
1.4. Fatigue limit or fatigue strength 7
1.5. SN curves up to 10^9 cycles 8
1.6. Deterministic prediction of the gigacycle fatigue strength 10
1.7. Gigacycle fatigue of alloys without flaws 12
1.8. Initiation mechanisms at 10^9 cycles 13
1.9. Conclusion 13
1.10. Bibliography 14

CHAPTER 2. PLASTICITY AND INITIATION IN GIGACYCLE FATIGUE . . . 17

2.1. Evolution of the initiation site from LCF to GCF 17
2.2. Fish-eye growth 20
2.2.1. Fracture surface analysis 20
2.2.2. Plasticity in the GCF regime 23
2.3. Stresses and crack tip intensity factors around spherical and cylindrical voids and inclusions 29
2.3.1. Spherical cavities and inclusions 29
2.3.2. Spherical inclusion. 31
2.3.3. Mismatched inclusion larger than the spherical cavity it occupies. 31
2.3.4. Cylindrical cavities and inclusions 33

2.3.5. Cracking from a hemispherical surface void 35
2.3.6. Crack tip stress intensity factors for cylindrical inclusions with misfit in both size and material properties 38
2.4. Estimation of the fish-eye formation from the Paris–Hertzberg law 42
2.4.1. "Short crack" number of cycles 47
2.4.2. "Long crack" number of cycles 48
2.4.3. "Below threshold" number of cycles 48
2.5. Example of fish-eye formation in a bearing steel 49
2.6. Fish-eye formation at the microscopic level 52
2.6.1. Dark area observations 53
2.6.2. "Penny-shaped area" observations 54
2.6.3. Fracture surface with large radial ridges 56
2.6.4. Identification of the models 59
2.6.5. Conclusion 62
2.7. Instability of microstructure in very high cycle fatigue (VHCF). . . . 62
2.8. Industrial practical case: damage tolerance at 10^9 cycles. 69
2.8.1. Fatigue threshold in N18 70
2.8.2. Fatigue crack initiation of N18 alloy 71
2.8.3. Mechanisms of the GCF of N18 alloy 73
2.9. Bibliography. 74

CHAPTER 3. HEATING DISSIPATION IN THE GIGACYCLE REGIME. 77

3.1. Temperature increase at 20 kHz 77
3.2. Detection of fish-eye formation 81
3.3. Experimental verification of N_f by thermal dissipation 83
3.4. Relation between thermal energy and cyclic plastic energy 85
3.5. Effect of metallurgical instability at the yield point in ultrasonic fatigue. 89
3.6. Gigacycle fatigue of pure metals 91
3.6.1. Microplasticity in the ferrite 95
3.6.2. Effect of gigacycle fatigue loading on the yield stress in Armco iron 97
3.6.3. Temperature measurement on Armco iron. 98
3.6.4. Intrinsic thermal dissipation in Armco iron 102
3.6.5. Analysis of surface fatigue crack on iron 105
3.7. Conclusion 109
3.8. Bibliography. 110

INDEX. 113