学位論概要(Summary)

題 目： Study on Fatigue Life Estimation Method under Variable Amplitude Loading of AISI 316 and Weldment Martensitic Stainless Steel of Repairing Materials for Cavitation 2RM2（AISI 316 及びキャビテーション溶接補修材マルテンサイト系ステンレス鋼 2RM2 における変動荷重下の疲労寿命評価手法に関する検討）

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The main objective of the current is to investigate fatigue damage behavior below the fatigue limit under variable amplitude loading of materials of AISI 316 and weldment martensitic stainless steel 2RM2 whose $S-N$ curve exhibit oblique hyperbola and bilinear shape on double logarithmic ordinate, and to survey influence of welding defect on fatigue properties of 2RM2 under constant amplitude, as well as to verify the precision of EN and KHK standards, and Modified Miner's and Haibach's approaches, which correspond to predictive approaches considering cycles below the fatigue limit for $S-N$ curve of oblique hyperbola (EN and KHK) and bilinear shape (remaining two approaches), and to establish rational fatigue damage or life predictive approaches for above-mentioned materials.

Fatigue tests under combined repeated high- and low amplitude loading corresponding to stress above and below the fatigue limit were conducted. In these tests, high stress amplitude was fixed at constant of 260 MPa whereas low stress amplitudes were varied ranging from 225 MPa to 80 MPa with various cycle ratios. On the basis of observation of fracture surfaces, all initiation sites originated at surface, which illustrates that application of linear cumulative fatigue damage rule is reasonable. Therefore, the calculated results indicate that both the EN and KHK standards overestimated the fatigue life when the number of cycles of low-amplitude loading in one block was small. With the stress level held constant, the fatigue life increased as the number of cycles of low-amplitude loading increased. Thus, it was demonstrated that low-amplitude loading following high-amplitude loading contributed to the fatigue damage. Under this loading condition, the damage reached saturation after a critical number of low-amplitude loading cycles. Damage saturation statement contributed by low-amplitude loading below the fatigue limit in one block was proved.

Additionally, to investigate whether more higher stress above the fatigue limit have effect on cumulative fatigue damage below, fatigue tests were performed by increasing high stress to 277 MPa under similar repeated two-step amplitude loading. The predictive approach below the fatigue limit under high stress of 277 MPa is more conservative than that of at 260 MPa, in other words, the former one is on left of later case on double logarithmic ordinate. In addition, the saturation cycles of low stress amplitude below the fatigue limit is less than that of at 260 MPa. In summary, cumulative fatigue damage behavior below the fatigue limit is significantly affected by high stress amplitude.

Finally, to verify the accuracy of proposed approaches for predicting fatigue damage for AISI 316, fatigue tests under multi-step and random-amplitude loading were carried out. Experimental results agree with predicted outcomes extreme well in proving tests with the maximum stress ≧ 277 MPa, in which evaluation of fatigue lives were on the basis of predictive line obtained by fix high stress at 277 MPa in repeated two-step amplitude loading tests; whereas, for assessing fatigue lives based on predictive line acquired by maintaining high stress at 260 MPa, scatter is larger than former cases. Anyhow, the proposed approaches can be applied in practical application combining with design fatigue curve (DFC) method.

Fatigue tests were conducted under constant amplitude loading in order to survey influence of welding defect on fatigue behavior in weldment martensitic stainless steel 2RM2. It is obviously observed that $S-N$ curve of 2RM2 of welding defect ruptured mode is beneath surface fractured mode, namely, welding defect have negative effect on fatigue strength. Based on the obtained outcomes, a simplified linear elastic fracture mechanics approach was used to predict fatigue life via ignoring fatigue crack initiation period that is negligible compared with fatigue crack propagation period in welding defects fracture mode. Moreover, the influence of threshold stress intensity factor K_{th} in small size of welding defect should be considered. Through normalized ordinate using K_{max}/K_{th}, the diagram of relationship between K_{max}/K_{th} and $N_f-\sqrt{area}$ can be used to predict fatigue life of 2RM2 under constant amplitude loading. Furthermore, the maximum size of welding defect for arbitrary return period can be evaluated on the basis of statistical extreme value approach.

Similarly, due to unclear precision of Modified Miner's and Haibach's approaches on evaluating cumulative fatigue damage or life under variable amplitude loading for 2RM2, fatigue tests were performed under repeated two-step amplitude loading by keeping high stress amplitude as constant of 650 MPa with varying low stress amplitude loading and cycle ratios. Low stress amplitude below the fatigue limit can contribute to fatigue damage to specimen after being subjected to high stress amplitude, moreover, the existed Modified Miner's and Haibach's approaches give inaccurate estimation because of cycle ratios effect. A critical number of cycles of low stress amplitude in one block that can give fatigue damage effectively, exceeding which the corresponding stress amplitude stop damaging to specimen, was proved and calculated on the basis of obtained data. It is extreme similar to that of AISI 316.

Analogously, fatigue tests were carried out under repeated four-step amplitude loading to verify applicable of proposed approach for 2RM2. Experimental and predicted results agree with each other with a slight conservative prediction. Stress amplitudes below the fatigue limit still behave detrimental character under random-liked loading pattern, thus they should be considered when carry out engineering anti-fatigue design. The proposed approach can be used to predict fatigue damage or life under variable amplitude loading involving cycles below the fatigue limit in weldment martensitic stainless steel 2RM2.