論 文 の 要 旨(Abstract)

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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　　As environmental protection has been paid more and more attention, clear energy such as hydroelectric and nuclear power generations are becoming increasingly popular because of they have not discharged harmful gases to atmospheric circumstance during operational period. For security operation of power generations, engineering anti-fatigue design is essential due to fatigue character of materials dominate service and maintenance period of components and structures employed in power generations. In addition, in service loading condition, these components and structures are subjected to variable amplitude loading conditions, and are generally designed to bear low-amplitude loading below the conventional fatigue limit with the intermittent application of a small number of cycles of high-amplitude loading. Such low-amplitude loading appears to be harmless to components, but unexpected failure has often occurred. Therefore, investigation into cumulative fatigue damage below the fatigue limit under variable amplitude loading in AISI 316 and weldment martensitic stainless steel 2RM2, whose application are exploited in cooling pipeline of nuclear power generations and repairing for cavitations formed on surface of turbine runners of hydroelectric power generations, is one of objectives in the current study. It is well known that welding defects form inevitably during preforming welding process, thus, influence of welding defect on fatigue strength of 2RM2 under constant amplitude has also been surveyed in the current study.

　　The reason why selected AISI 316 and 2RM2 as experimental materials is that $S-N$ curve of former and latter materials exhibit oblique hyperbola and bilinear shape on double logarithmic coordinate system, respectively. There are two fatigue damage or life predictive approaches for oblique hyperbola $S-N$ curve: a High Pressure Gas Safety Institute of Japan (KHK) standard that can be used to evaluate fatigue damage below the fatigue limit by expanding the $S–N$ diagram from 10^7 to 10^8 cycles and passing a vertical line from the load corresponding to 10^8 cycles to half of that load, and a European (EN) standard that can be used to predict the fatigue damage below the fatigue limit by drawing an oblique line with a slope of -0.1

from 2×10^6 to 10^8 cycles. Similarly, two extreme famous laws can be utilized to evaluate fatigue damage below the fatigue limit for bilinear relationship who are Modified Miner's and Haibach's laws, detail of whom in portion below the fatigue limit of $S-N$ curve are extending original $S-N$ curve from knee point with same slop of original $S-N$ (k); and extending original $S-N$ curve from knee point with slop of $1/(2/k-1)$. However, effect of cycle ratios between cycles of high and low amplitude loading corresponding to stress above and below the fatigue limit is unclear in aforementioned approaches. Hence, cycle ratios effect demand to be clarified by conducting fatigue tests under repeated two-step amplitude loading conditions with varying cycle ratios.

Firstly, fatigue tests were performed under constant amplitude loading using AISI 316 to determine the predictive line below the fatigue limit on the basis of EN and KHK standards. Next, combined high- and low-amplitude loading corresponding to stress above and below the fatigue limit tests with various cycle ratios were carried out in order to verify the precision of EN and KHK standards. Test results indicate that low-amplitude loading following high-amplitude loading contributed to the fatigue damage and affected fatigue life. Furthermore, both the EN and KHK standards gave inaccurate evaluation of fatigue life because of the effect of cycles of low-amplitude loading below the fatigue limit in one block. Fatigue damage at saturation in one block contributed by low-amplitude was proved. Moreover, to understand whether more higher stress affected cumulative fatigue damage behavior, fatigue tests were also conducted under above-mentioned loading pattern by increasing high stress amplitude above the fatigue limit to 277 MPa (former case of 260 MPa), predictive line below the fatigue limit obtained by fictitious fatigue life approach in high stress of 277 MPa shift to left compared with that of at 260 MPa, not only predictive line was affected by high stress but also critical cycles of low stress that can contribute fatigue damage effectively in one test block was less than previous case. Finally, rational approaches for evaluating fatigue damage below the fatigue limit for nonlinear $S-N$ curve were established and their accuracy have been validated by multi-step and random-amplitude loading tests.

For the purpose of acquiring basic $S-N$ information in 2RM2 of surface and welding defect fracture mode, fatigue tests were carried out under constant amplitude loading. Fatigue life of welding defect fracture mode are shorter than that of surface fracture mode. 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.

To validate accuracy of Modified Miner's and Haibach's laws for assessing fatigue damage considering cycles below the fatigue limit, fatigue tests were conducted under previously elaborated repeated two-step

amplitude loading conditions. 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. Finally, a new proposed approach was constructed based on repeated two-step amplitude loading tests, and the approach agrees with Corten-Dolan method, its applicable has been verified by conducting repeated four-step amplitude loading tests.