Frictional Behavior of Fe-based Cladding Candidates for PWR

Young-Ho Lee [a*], Thak Sang Byun [b], Hyung-Kyu Kim [a]
[a] *Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong, Daejeon, Korea, 305-353*
[a] *Oak Ridge National Laboratory, Oak Ridge TN 37831, USA*

[*] *Corresponding author: leeyh@kaeri.re.kr*

1. Introduction

After the recent nuclear disaster at Fukushima Dai-ichi reactors, there is a growing consensus on the development of new fuel systems (i.e., accident-tolerant fuel, ATF) that have high safety margins under design-basis accident (DBA) and beyond design-basis accident (BDBA). A common objective of various developing candidates is to archive the outstanding corrosion-resistance under severe accidents such as DBA and DBDA conditions for decreasing hydrogen production and increasing coping time to respond to severe accidents. ATF could be defined as new fuel/cladding system with enhanced accident tolerant to loss of active cooling in the core for a considerably longer time period under severe accidents while maintaining or improving the fuel performance during normal operations [1-3]. This means that, in normal operating conditions, new fuel systems should be applicable to current operating PWRs for suppressing various degradation mechanisms of current fuel assembly without excessive design changes. When considering that one of the major degradation mechanisms of PWR fuel assemblies is a grid-to-rod fretting (GTRF), it is necessary to examine the tribological behavior of various ATF candidates at initial development stage. In this study, friction and reciprocating wear behavior of two kinds of Fe-based ATF candidates were examined with a reciprocating wear tests at room temperature (RT) air and water. The objective is to examine the compatibilities of these Fe-based alloys against current Zr-based alloy properties, which is used as major structural materials of PWR fuel assemblies.

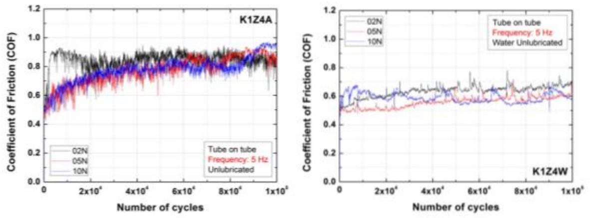
2. Experiments

In this study, two kinds of Fe-based ATF candidates (i.e., FeCrAl and ODS alloys) and a current Zr-based alloy were prepared with dimension of 9.5 mm in outer diameter and 6 mm in length. Mean surface roughness is maintained with about 0.3 μm. The reciprocating wear tests were performed with a conventional wear tester (DUCOM® TR-282), which has a tube-on-tube geometry with right angle arrangement. Three kinds of contact force (i.e., 2, 5 and 10 N) were applied with frequency of 5 Hz. All reciprocating wear tests were carried out at RT air and water with fixed reciprocating stroke and number of cycle with 1 mm and 1 x 10^5, respectively. During the reciprocating wear tests, coefficient of friction (COF) was continuously monitored to determine the relationship between the severe wear initiation and the variation of COF values.

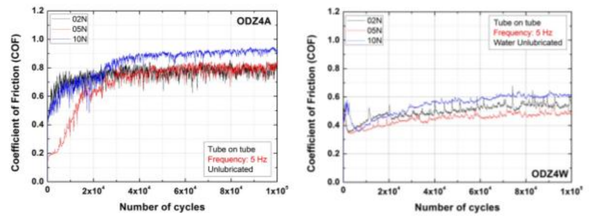
3. Results and Discussion

3.1 Frictional Behavior

Typical results of frictional behaviors in two kinds of Fe-based alloys against current Zr-based alloy are shown in Fig. 1. In this results, the variation of COF values was negligible with increasing applied force in both air and water conditions. Also, mean COF values under water condition have relatively lower when compared with the result of air condition.



(a) FeCrAl against Zr alloy (Air & Water)

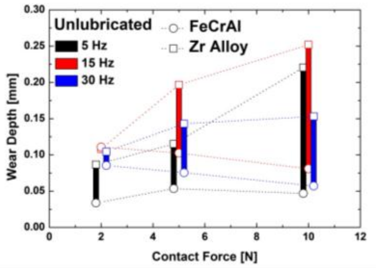


(b) ODS against Zr alloy (Air & Water)

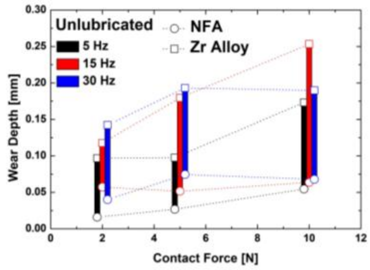
Fig. 1. Typical results of frictional behavior under reciprocating sliding at each test condition.

3.2 Wear Depth

Wear depth results were obtained from bottom and top samples and the measurement results of maximum wear depth and the difference between both samples in RT air were described in Fig. 2. When considering compatibilities of Fe-based ATF candidates against current Zr-based alloy, the enlarged difference (i.e., length of bar between two values) in wear depth could be considered as one-side localized wear among two samples. Wear depth in RT air was weakly dependent on Fe-based candidates: no significant differences were found in wear depth variation.



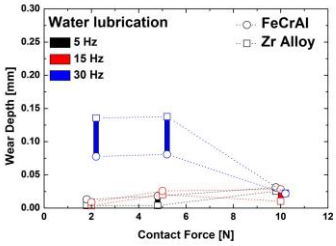
(a) FeCrAl/Zr



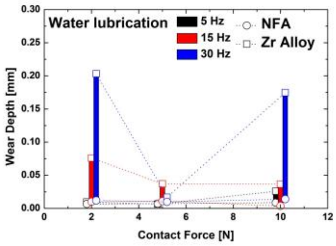
(b) ODS/Zr

Fig. 2. Typical results of frictional behavior under reciprocating sliding in RT air.

Under RT water as shown in Fig. 3, however, wear depth of both ATF candidates and coupled Zr-based alloy has a strong dependency of their different mechanical properties. The wear depth of two Fe-based alloy was negligible and wear depth increase was dominant in Zr-based alloy. This result indicated that the severe plastic deformations and localized wear were mainly happened in Zr-based alloy, which are used in spacer grid materials of current PWR fuel assembly.



(a) FeCrAl/Zr



(b) ODS/Zr

Fig. 3. Typical results of frictional behavior under reciprocating sliding in RT water.

3. Summary

The reciprocating wear behaviors of Fe-based accident-tolerant fuel cladding candidates against current Zr-based alloy has been studied using a reciprocating sliding wear tester in room temperature air and water. Frictional behavior and wear depth were used for evaluating the applicability and compatibilities of Fe-based candidates without significant design changes of PWR fuel assemblies. Consequently, it is difficult to apply these Fe-based alloys to current Zr-based structural materials because of their high mechanical strength. So, it is necessary to improve the mechanical properties of current Zr-based alloy or to consider new materials for supporting these Fe-based cladding candidates for improving GTRF resistance in normal operating conditions of current PWRs.

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