Comparison Study on Air Oxidation Behavior of Advanced Super-Alloys In Elevated Temperatures

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Summary

Nickel based Superalloys play an important role in ensuring the integrity, durability and long-term performance of nuclear reactors. They are used in the heat transfer and cooling systems as well as in the reactor vessel internals. The air oxidation resistance of four different nickel based alloys including Alloy X750, Alloy 230, Alloy 625SQ, and HASTELLOY N at 600, 800, and 1000 °C has been evaluated. Morphology of surface and cross-section of oxide scales were studied using Scanning Electron Microscope equipped with Energy Dispersive X-ray Spectroscopy. We also used X-ray Diffraction to identify oxide phases formed on surface of samples. Furthermore, Microtexture of as received alloys and existing oxide phases and also microtexture of starting samples were analyzed.

1. Introduction

Large energy consumption which are mostly based on fossil fuels such as coal, oil & natural gas is a critical issue in terms of energy security. In spite of fossil resources, the rate of energy consumption is increasing year by year. On the other hand, global warming due to greenhouse gases (GHG) emissions, especially carbon dioxide, has become a serious issue [1]. In this condition, nuclear energy can play an important role in decreasing concerns over energy security and global warming issues as well [2]. Beside all the advantages of nuclear energy, there are still some concerns over this important resource of energy. The most important concerns are production efficiency and safety of nuclear reactor systems. To overcome production efficiency of nuclear reactors, Generation IV reactors have been designed and are supposed to be serve the community in 2030. The supercritical water-cooled reactor (SCWR) is one of the six reactor technologies selected for research and development under the Generation IV program [3]. Due to aggressive SCWR environment, lots of research is conducted to propose candidate materials which are safe and possesses high resistance against failures such as high temperature, radiation, high stress and corrosive environments. From this perspective, it can be understood that finding materials applicable for the SCWR core condition is an essential task in the SCWR development [4].Nickel-based super alloys have an exceptional combination of high temperature strength, toughness, and resistance to degradation in corrosive or oxidizing environments [5].

One of the regular failures in high temperature and corrosive environments such nuclear reactors is oxidation. Thus, the objective of this comparison study is to select appropriate materials for further failure analysis in more severe operating conditions. In this regard, air oxidation tests have been conducted on four nickel alloys and Morphology of surface and cross-section of oxide scales were studied using Scanning Electron Microscope equipped with Energy Dispersive X-ray Spectroscopy. Consequently, X-ray Diffraction was used to identify oxide phases formed on surface of samples. Furthermore, Microtexture of as received alloys and existing oxide phases and also microtexture of starting samples were analyzed.

2. Experimental Procedure

2.1 Microtexture evaluation of as-received samples and oxidation process

In order to know the microtexture and also grain size of starting samples, Orientation Image Mapping (OIM) was applied. Fig. 1 shows the EBSD images of as-received samples. As it is observed, the grain size of starting alloys were different from each other. Furthermore, it seems there are some preferred orientation in the as-received samples. All of the samples were cut in a same size and then oxidized in three different temperatures including 600, 800, 1000 ^{0}C.

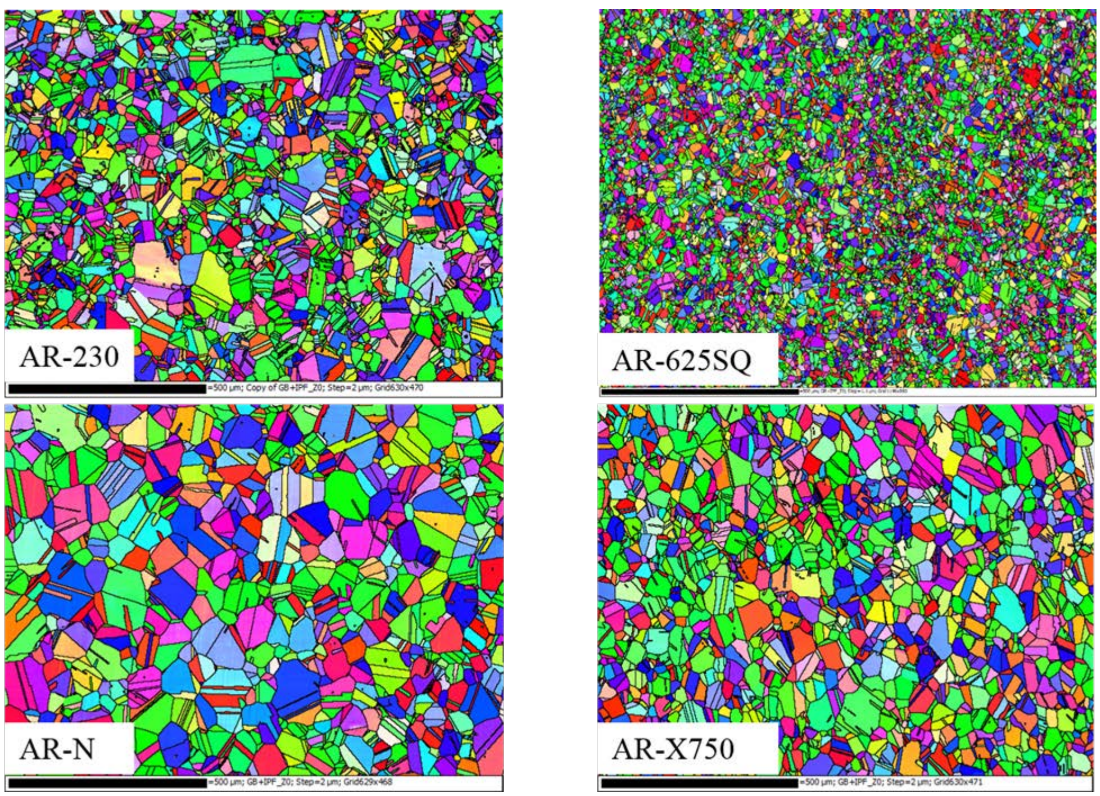

Fig. 1. Microtexture of as-received samples

2.2. Morphology of oxidized alloys

In order to study the morphology of oxidized samples scanning electron microscopy (SEM) was employed. Fig. 2 shows the oxidation evolution at three temperatures for all alloys. As it is obvious, there is not any specific oxidation in the grain and on the grain boundaries until 1000 ^{0}C. Fig.2.a,b & c reveal that Alloy 230 is fairly oxidized at 1000 ^{0}C but the oxide scale is not very coherent. It seems alloy 230 is rather resistant to air oxidation.

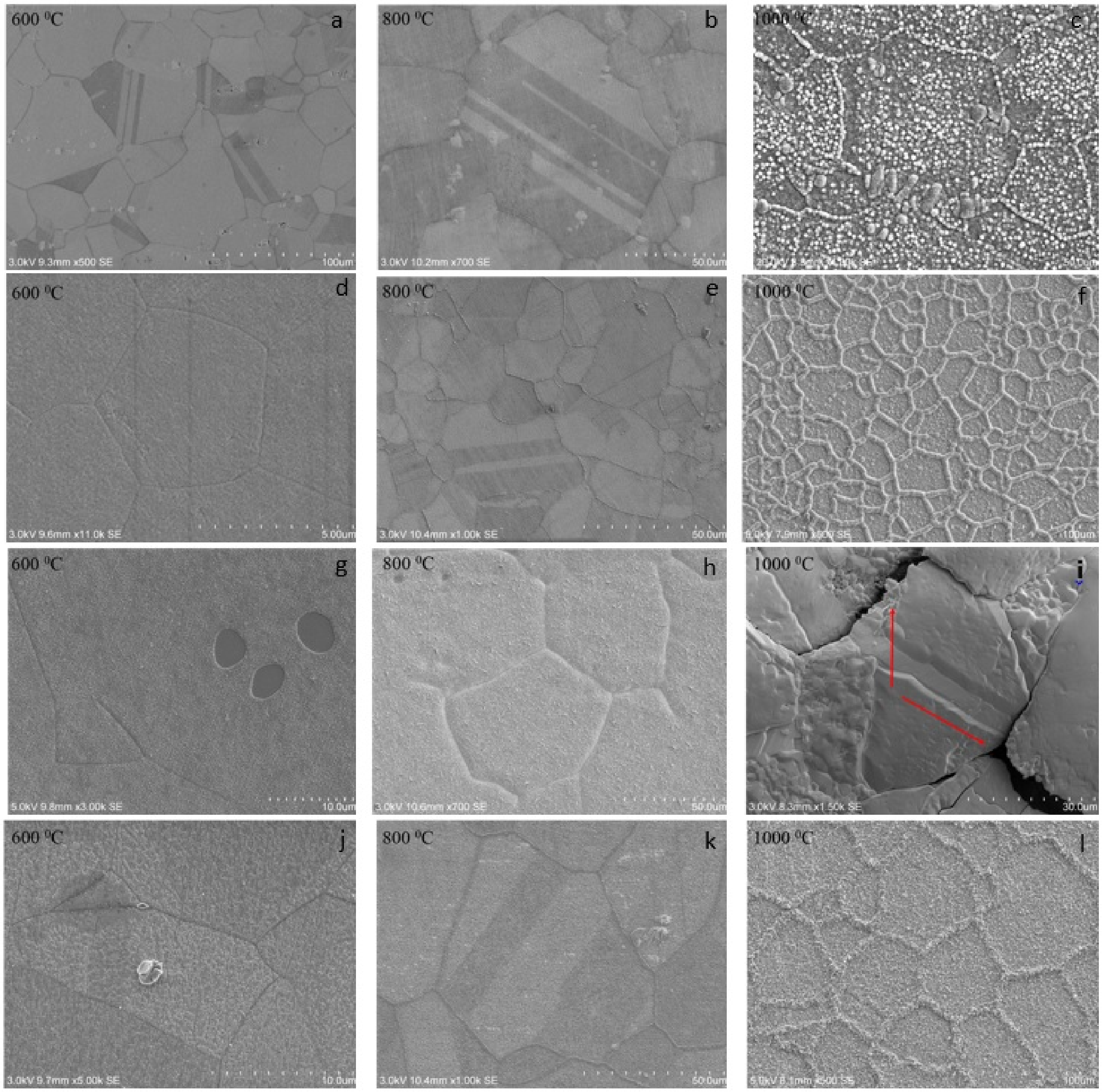

Fig.2. Morphology of oxide scale at three different temperatures for alloys 230 (a) (b) (c), 625SQ (d) (e) (f), N (g) (h) (i) and X750 (j) (k) (l)

As Fig.2.d,e & f shows oxidation starts in grain boundaries at 800 ^{0}C for alloy 625SQ and at 1000 ^{0}C grain boundaries are heavily oxidized. It is obvious that grain boundaries are preferred sites for oxide formation due to high energy of grain boundaries. For alloy N, the morphology of oxides are different and they are dendritic. Fig.2.g,h & i states that grains are more oxidized in comparison with grain boundaries. Also, at 1000 ^{0}C a thick oxide layer covers all the surface of the sample. Furthermore, some spallation are observed at 1000 ^{0}C. Fig.2.j,k & l illustrate that oxidation has started at 1000 ^{0}C in alloy X750 and the rate of oxidation in both grains and boundaries are somehow equal.

2.3. Cross section observation and EDS spectroscopy of oxide scales

Fig. 3 shows cross section observation of substrate and oxide layer. As it is obvious a coherent and adherent oxide layer is formed on the surface of substrate. Furthermore, elemental distribution maps reveals that the dominant available oxide phase is chromium oxide.

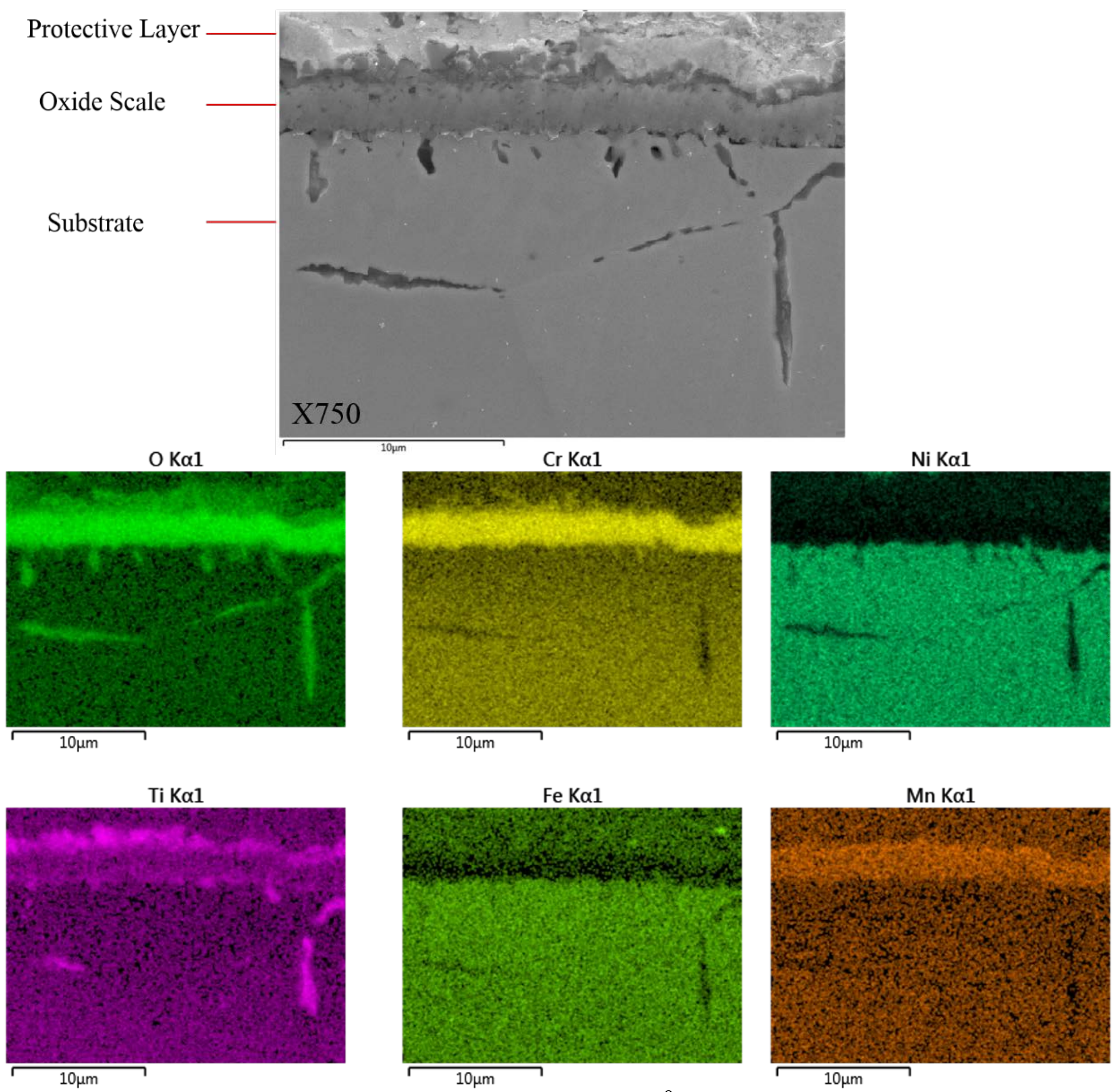

Fig 3. Cross section image of oxidized sample at 1000 ^{0}C and distribution of elements

2.4. Macrotexture of as-received samples and oxide scales

To investigate the texture of as-received samples and oxide scale, X-ray technique was employed to find out which oxide phases are available. Then macro-texture of starting and oxidized samples was found out in table 2.

Table 2. Dominant texture of as-received texture and corresponding oxide texture.

Alloys	Dominant Textures
AR-230	{110} {310}
230 Oxide	{100}
AR-625SQ	{110} {310}
625SQ Oxide	{110} {100}
AR-N	{100} {110} {111} {410}
N Oxide	{100}
AR-X750	{110} {310}
X750 Oxide	{100}

3. Conclusion

To sum up, it seems HASTELLOY N could not be considered for further processing. However, Alloys 230, 625SQ and X750 could be appropriate candidate. In order to increase oxidation resistance of these alloys, post processes such texture tailoring and grain boundary engineering would improve their resistance over failures.

4. References

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