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Microstructure analysis for Functionally Graded Composite steel after hot extrusion

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1. Introduction

New reactor designs, such as small and modular reactor (SMR) systems and Generation IV nuclear reactor systems will be commissioned to replace and expand the existing nuclear reactor systems pressurized water reactors, boiling water reactors, and Canadian deuterium uranium type reactors. These reactors should be competitive, safe, proliferation resistant, and meet the criteria of sustainability. Generation IV reactors have many advantages over light water reactors. The advantages of the fast reactor design come from using liquid metal as the coolant. The liquid metal coolants used in fast reactors tend to have more attractive thermal-hydraulic properties and atmospheric pressure advantages than more traditional coolants, such as water. Liquid metal coolants such as lead, lead-bismuth eutectic (LBE), and sodium also have the benefits of higher thermal conductivities and heat capacities than most other coolants.

Liquid metal fast breeder reactors, such as the lead-cooled fast reactor and the sodium-cooled fast reactor, are candidates for the next generation of nuclear reactors. An advantage of these types of reactors is that the liquid metal has high heat transfer properties, which allow the reactor to be operated at considerably low pressures and high temperatures. Liquid sodium and LBE coolants can be used for fast reactor cores because of their high cooling capabilities. These properties are important factors in fast reactor design. Sodium has a lower melting temperature than LBE and better thermophysical properties, but it is much more chemically active and has a lower boiling point, whereas LBE is chemically inert but highly corrosive and can penetrate structural and cladding material. Liquid lead (Pb) and LBE alloys are the candidate coolants for fast breeder reactors and accelerator driven systems, which are being developed to extract power through removal of the minor actinides of the nuclear waste from fission reactors.

Heavy liquid metals are adequate for transmutation of nuclear waste and spent fuel, as their heavy nuclei make it possible to obtain a very fast neutron spectrum, and nuclear safety and nuclear waste problems are important issues to consider [2,3]. Long-lived minor actinides, such as neptunium or americium, which occur in nuclear waste, can be burned.

Most research in the field of LBE cooled fast reactors loops is focused on stability and experimental investigation of natural circulation [4–6]. Many experimental investigations and theoretical analyses have been conducted for symmetrically heated and cooled loops [7–9]. Liquid metal loops have been used to produce the experimental data for thermal-hydraulic tests, which were conducted using a realistic height integral test facility. To ensure the collection of basic data for the design of the pressure release loop and to understand the pressure change characteristics and circulating characteristics of liquid metal coolant in a natural circulation system, the experiments were conducted under both accident and normal conditions.

The goal of this paper is to further develop the functionally graded metallic composite This functionally graded metallic composite will ultimately be available to be used as piping and fuel cladding in a lead-bismuth cooled nuclear reactor. The tasks provide a detailed description of the work completed within this paper. Complete a detailed microstructural analysis of the piping product using optical microscopy. Optimize the microstructure and mechanical properties of the T91 and Fe12Cr2Si layers in the piping product through heat treatment.

2. Experimental

2.1 Materials

The materials science tetrahedron shows that there is an interrelation between the processing, properties, performance, and structure for every material. The metallic composite in this study consists of a T91 ferritic/martensitic structural steel weld overlaid with a corrosion resistant Fe12Cr2Si layer. The T91 steel provides the mechanical strength while the Fe12Cr2Si layer acts as a barrier for corrosion. Table 1 shows the ASTM chemistry.

2.2 Weld Overlay

The weld wire and F91 billets were sent to Arc Applications in York, PA for weld overlaying. Billets were first fitted with carbon steel endcaps to allow the weld overlay process to run past the end of each billet, thereby increasing the yield of the process. A Bor-Tech automatic spiral welding machine outfitted with a GTAW electrode and a 61 cm (24") stroke length was used to apply a uniform, spiral coating of Fe-12Cr- 2Si alloy onto two of the billets in one pass per layer.

Table I. Shown above is the chemical analysis of the FeCrSi and T91 steel

Ferritic/Martensitic Steel		
Sample Identification	T91	FeCrSi
	wt%	wt%
C	0.10	0.007
S	<0.01	0.001
N	0.057	0.002
Fe	89	85.5
Cr	8.39	12.2
Si	0.32	2.12
P	0.019	0.0059
Al	0.0061	0.03
Mg	0.47	0.0024
Ni	0.28	0.013
W	0.008	0.004
V	0.21	0.0039
Mo	0.92	0.0029
Co	0.15	0.032

2.3 Co-extrusion

The billets were cleaned, and a 2.54cm (1") fillet was turned on the OD of each billet to allow for easier insertion into the extrusion die, as shown in Figure 3-14. The billets were then preheated to 816'C (1,500'F) in a reducing gas furnace for one hour, followed by an induction preheat to between 1,193 and 1,224 ºC (2,180 - 2,2360F) for 15 minutes.

3. Results and Discussion

3.1. Microstructure of FGC tube

Figure 1 was shown that microstructure of Fe-12Cr-2Si materials on the OD cladding. In the inner part, it is observed the ferritic/martensitic phase. And, it is observed the prior austenitic grain boundary at FeCrSi.

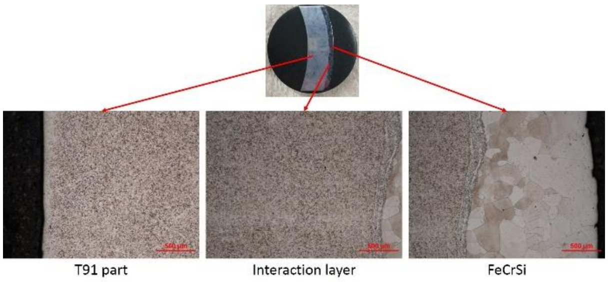


Fig. 1 Optical Microscopy image for OD cladded T91 specimen

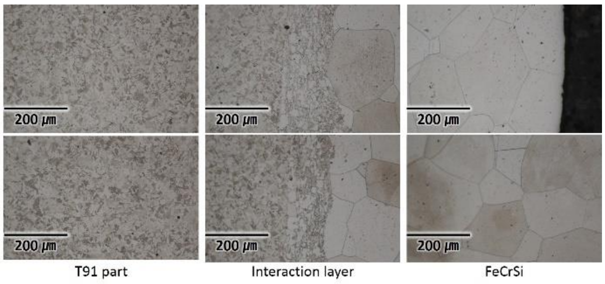
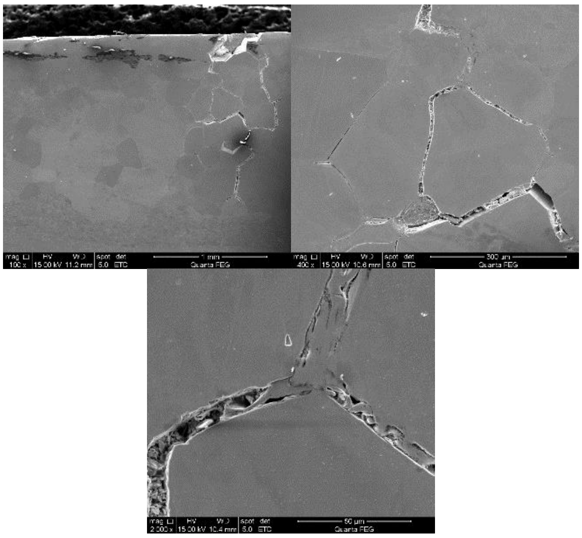


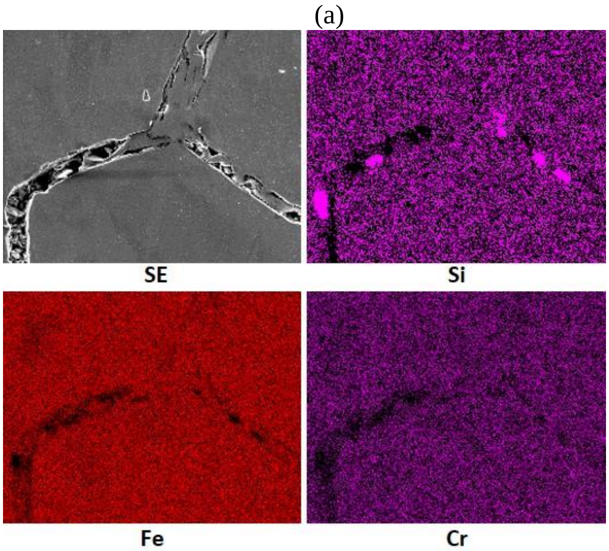
Fig. 2 Optical Microscopy image for OD cladded T91 specimen

Figure 2 was shown that microstructure of Fe-12Cr-2Si materials on the OD cladding. In the inner part, it is observed the ferritic/martensitic phase. And, it is observed the prior austenitic grain boundary at FeCrSi. Each section was different from other layer.

3.2. Crack on Overlay weld materials



(a)



(b)

Fig. 3 (a) SEM image for crack on OD cladded T91 (b) EDS mapping image for crack on OD cladded T91

Figures 3 (a) was shown that microstructure of Fe-12Cr-2Si materials on the T91 with a small amount of intergranular pores tend to be more prone to grain boundary cracking after hot extrusion processing. At the next page, there are SEM image for detailed analysis. And, figures 3 (b) was shown that EDS mapping of crack of FeCrSi at OD cladded T91. There is similar distribution of Fe, Cr, Si in the specimen. In those figures, there are some cluster form of silicon. According to literature, Si segregation and silicon rich phase can be formed at high temperature environment. There is not observed the significant difference about Mn, S, I, P. For the detailed analysis, TEM and dp pattern analysis need to perform.

According to previous literature, Owing to the considerable deformation associated with extrusion operations, a number of defects can occur in extruded products. Surface cracking from high workpart temperatures that cause cracks to develop at the surface. They often occur when extrusion speed is too high, leading to high strain rates and associated heat generation.

Otherwise, the depletion of the grain boundaries by silicon was observed under all conditions except for the samples annealed at 800 ◦ C for 100 h with the highest grain size.

4. Conclusions

In this study, microstructure analysis were conducted for investigating the Functionally Graded Composite tube. From this study, the following conclusions are drawn:

1. Thickness of FeCrSi layer on OD cladding is about 1500 um after hot extrusion.
2. The microstructure of Fe-12Cr-2Si materials on the OD cladded T91 with a small amount of intergranular pores tend to be more prone to grain boundary cracking after hot extrusion processing.
3. There are key factors for cracking at overlay weld materials. i) Grain boundary segregation ii) Surface cracking by hot extrusion iii) Hot cracking iv) reheat cracking v) crack of overlay weld metal (residual stress)

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