

Development of Multi-Walled Cold Drawing Process for Improved Accident Tolerant Fuel Cladding in Light Water Reactors

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Abstract

- The nuclear fuel claddings used in light water reactors (LWRs) consist of zirconium and a small number of metals.
- However at the time of the accident in Fukushima, Japan, zirconium alloy (Zr-alloy) cladding reacted with high-temperature steam in **loss of coolant accident (LOCA)** and a large amount of hydrogen gas was generated.
- In order to solve these problems, various studies are underway to development of the **accident-tolerant fuel (ATF)** cladding.
- In this research, a **drawing process** was used to improved mechanical strength under high temperature conditions by using stainless steel 316L (SUS 316L) tube inside and outside of the existing ZIRLO cladding.
- The development of **Multi-Walled Drawing process** which is very simple and performs at room temperature can be mass-produced using existing Zr-alloy cladding.

Experimental

➤ Swaging process

- Swaging is a process that produces an outer diameter of the desired size.
- Swaging process should be pre-ceded, about 15cm in length of the multi-walled tube to hold the front part when drawing.



Figure 1. Swaging process machine

➤ Drawing process

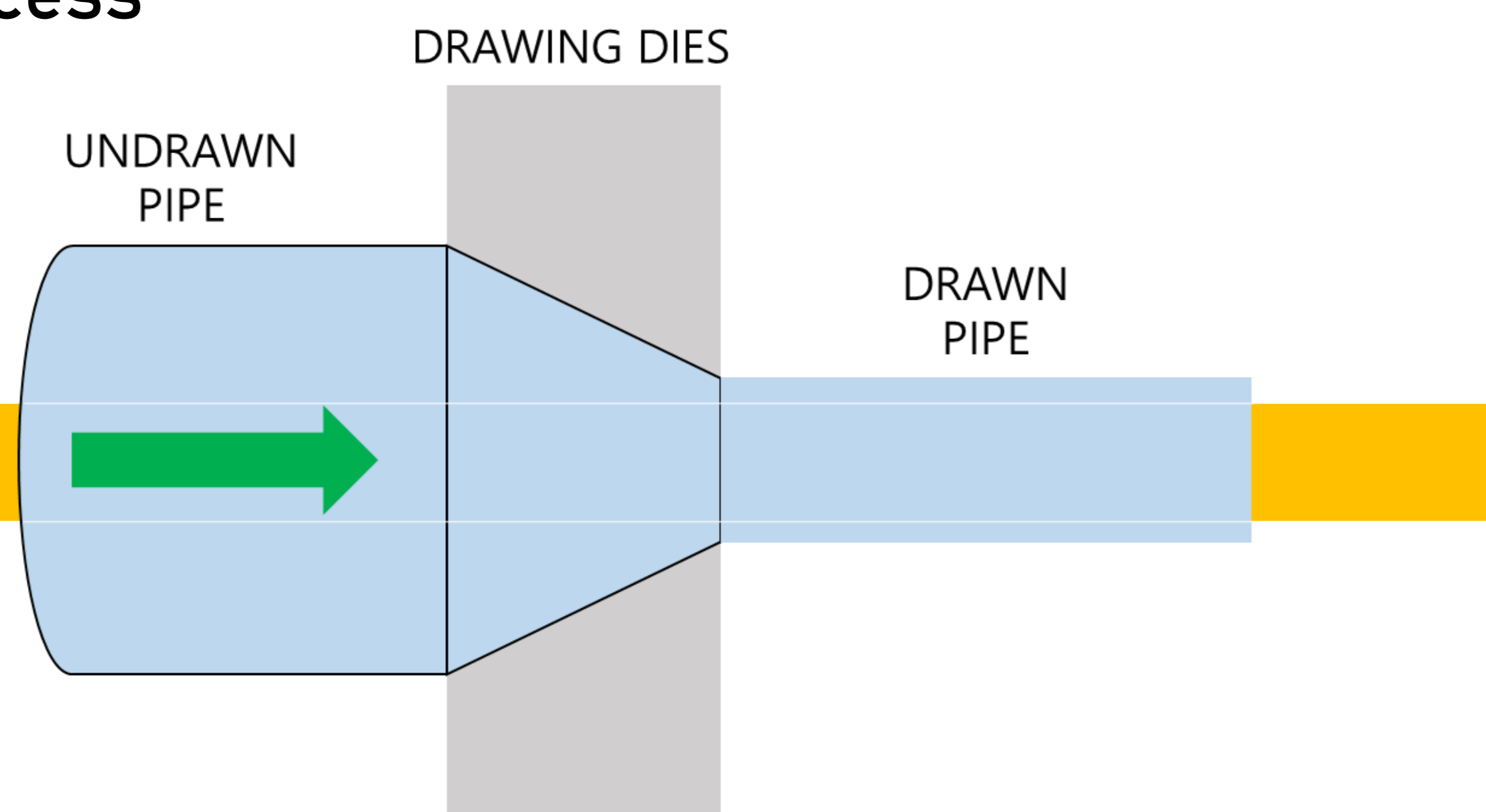


Figure 2. Schematic diagram of the drawing process

- Drawing is a metalworking process which uses tensile forces to stretch metal, glass or plastic.
- Swaging process should be preceded, about 15cm in length of the multi-walled tube to hold the front part when drawing.

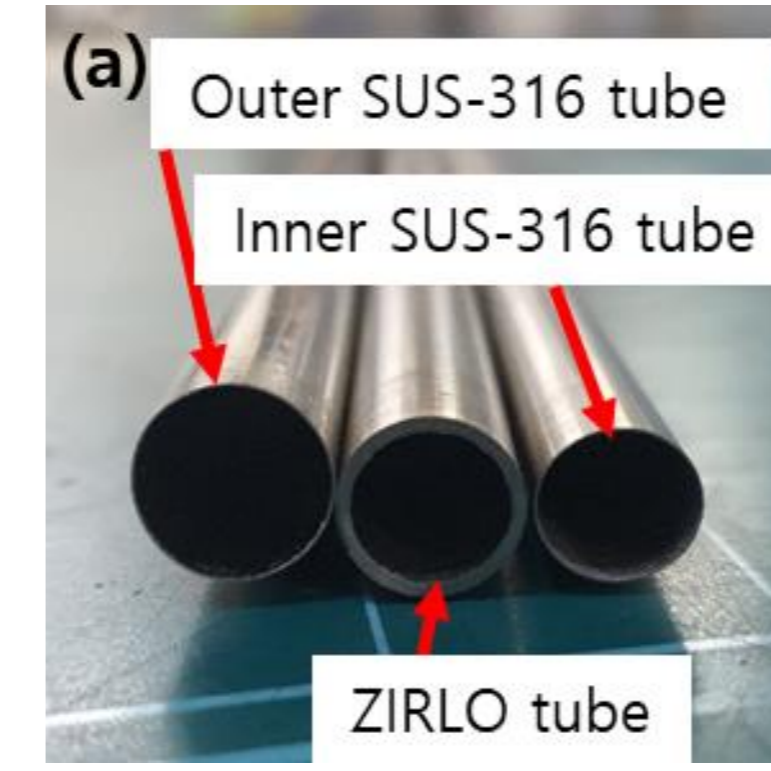
➤ Straightening process

- In the process of drawing, the tube is subjected to external force, is warped depending on the stress level.
- To solve this problem, straighten the cladding using a straightening machine.

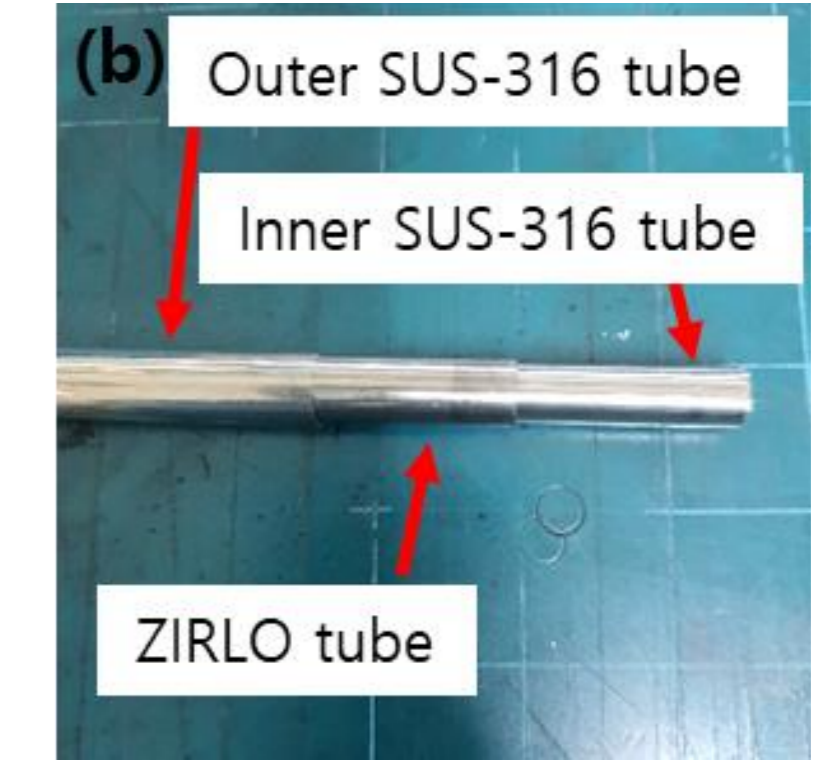


Figure 3. Straightening process machine

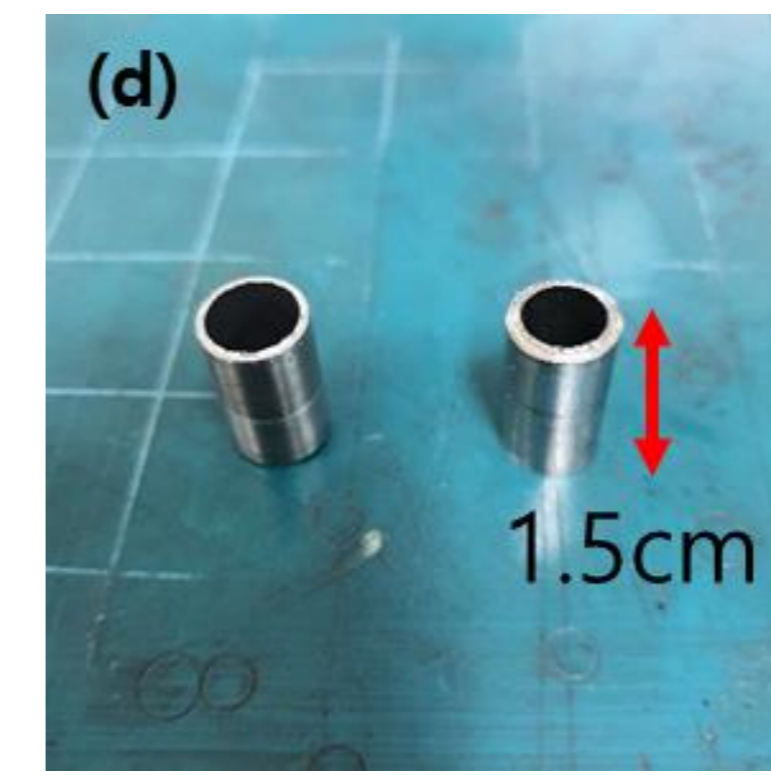
< Material preparation >



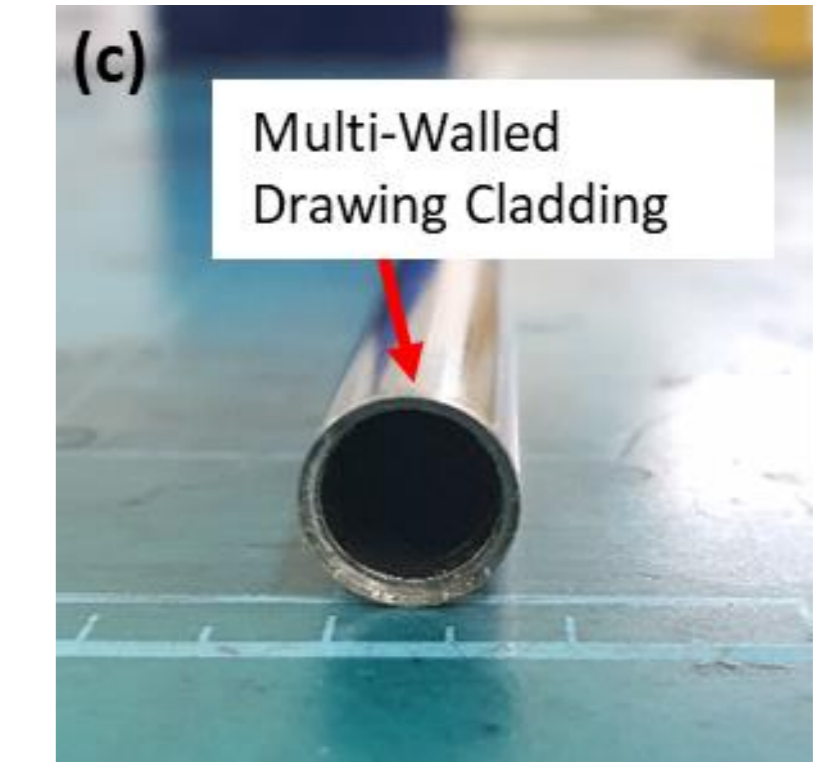
< Swaging after tube insertion >



< Heat treatment sampling >



< Drawn multi-walled tube >



Results

➤ OM (Optical Microscope)

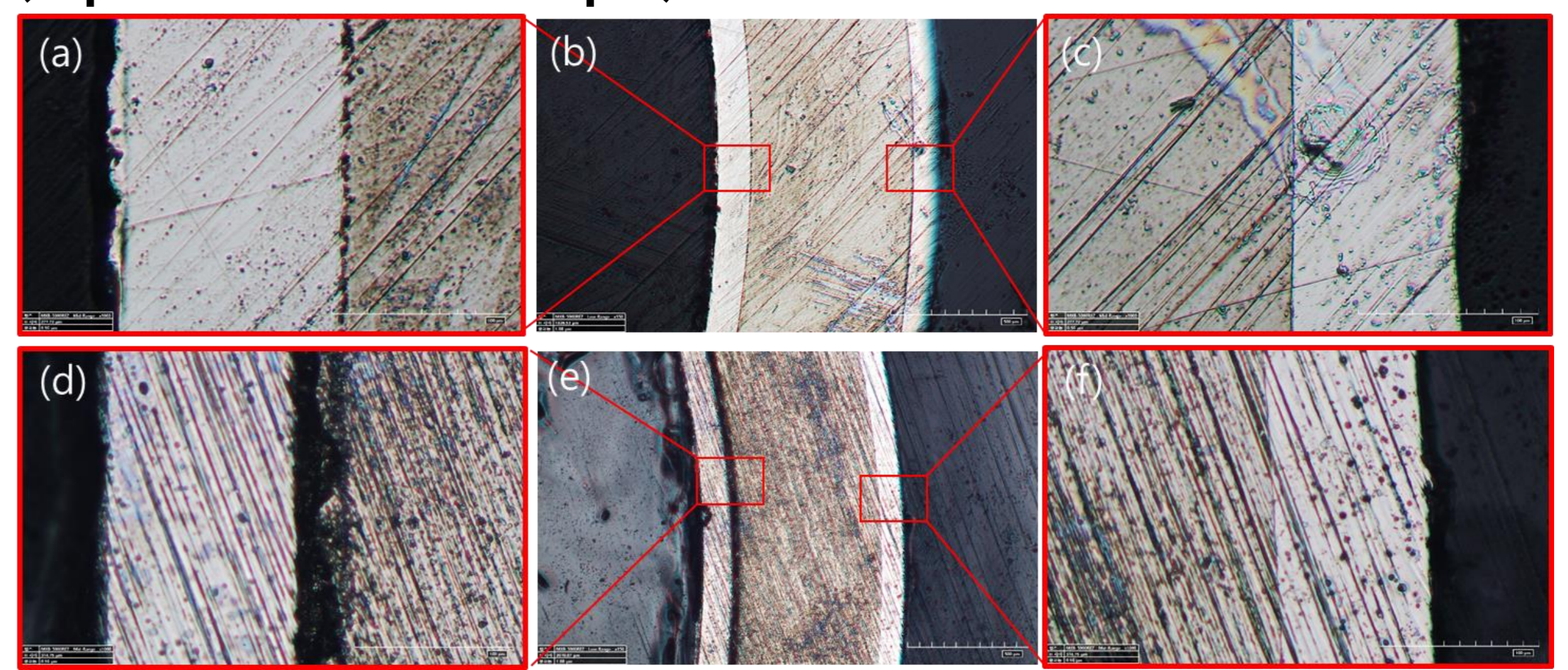


Figure 4. Cross-sectional OM image (a) to (c) for 9.4Φ MWDC, and (d) to (f) for 9.5 Φ MWDC

➤ SEM (Scanning Electron Microscope)

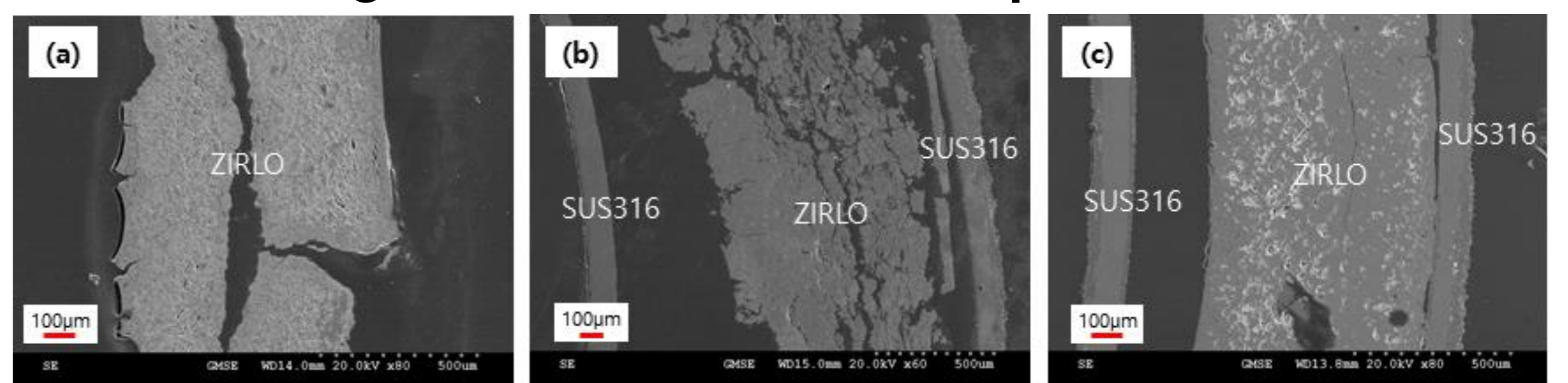


Figure 5. SEM cross-sectional images of samples after 1200°C heat treatment (a)ZIRLO (b)9.5Φ MWDC (c)9.4Φ MWDC

➤ Weight change

	ZIRLO	9.5Φ MWDC	9.4Φ MWDC
Weight change at 600°C(mg)	1662→1665 (0.18% increase)	1980→1982 (0.10% increase)	2257→2258 (0.04% increase)
Weight change at 900°C(mg)	1510→1551 (2.72% increase)	2577→2612 (1.36% increase)	2344→2373 (1.24% increase)
Weight change at 1200°C(mg)	1687→2275 (34.85% increase)	2071→2509 (21.15% increase)	2141→2504 (16.95% increase)

➤ EDS (Energy Electron Microscopy)

Element	ZIRLO	9.5Φ MWDC	9.4Φ MWDC	
O K	Weight%	26.55	14.96	12.17
	Atomic%	67.34	50.09	44.14
Zr L	Weight%	73.45	85.04	87.83
	Atomic%	32.66	49.91	55.86
Totals	200	200	200	

Conclusions

In conclusion, it is expected that better accident-tolerant fuel (ATF) can be derived if the interface problem between tubes is solved in **Multi-Walled Drawing Cladding (MWDC)** production.

References

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