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Induction Melting of Radioactive Stainless Steel Waste for Decommissioning of NPPs

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1. Introduction

Radioactive metal wastes were generated during the decommissioning process of the nuclear power plant which are mainly metal structures inside the reactor building. Metal melting is considered to effectively process with volume reduction of radioactive metal wastes. Melting of radioactive metal wastes generates slag composed of oxide, if properly controlled, can significantly reduce the concentration of radionuclides in ingots. During the melting process, radionuclides differ in thermodynamic stability according to slag composition and temperature and maintenance time, and are distributed to ingots, slags, dust, etc. Therefore, the selection of slag composition that can distribute radionuclides to slag and dust is important. The distribution behavior of cobalt was investigated by melting at about 1,700°C for stainless steel and adding Fe_2O_3, CaF_2, and MgO respectively in basic composition of CaO-SiO_2-Al_2O_3.

2. Methods and Results

2.1 Induction Melter

The Lab. scale induction melter consists of a furnace, induction heaters, and coolers. Fig 1 shows the lab. scale induction melter. Induction melter adopted IGBT with high frequency waves from induction heat sources which use 3-phase 380 V with output of 30 kW. A crucible surrounded by induction coils was installed inside the container of furnace. The melting crucible uses a magnesia crucible suitable for melting the metal specimen, and is designed to be 100mm in diameter and 150mm in height. Temperature measurements inside crucible use an infrared thermometer (model GM-2200 of BENETECH).

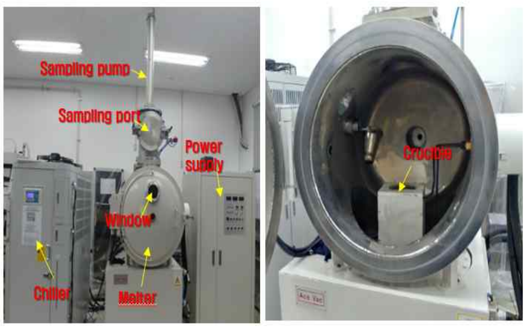

Fig 1. Lab scale induction melter

2.2 Experimental Procedure

The Co simulant was used as 5.0g of Co_3O_4 and 2kg of stainless steel was used as specimens. The tests were conducted to investigate the composition of slag with optimum distribution ratio of Cobalt by adding 20% of slag with Fe_2O_3, CaF_2, and MgO to the basic slag composition.(Table 1) The average temperature of stainless steel was maintained at approximately 1,700°C, and the concentration of cobalt was analyzed with ICP-MS by taking samples three times every 20 minutes.

Table 1: Slag composition for Co partitioning

#	Slag Composition(wt%)
2-1	$CaO(40\%)$-$SiO_2(30\%)$-$Al_2O_3(10\%)$-$Fe_2O_3(20\%)$
2-2	$CaO(40\%)$-$SiO_2(30\%)$-$Al_2O_3(10\%)$-$CaF_2(20\%)$
2-3	$CaO(40\%)$-$SiO_2(30\%)$-$Al_2O_3(10\%)$-$MgO(20\%)$

2.3 Fe_2O_3 addictive test for Co partitioning in slag

At the beginning of the melting of stainless steel, cobalt mainly stayed at the upper part and showed the largest amount distributed to slag. After about 20 minutes, the concentration of cobalt was reversed and tended to be more distributed in the lower part, but after 40 minutes, the cobalt was again distributed in the upper part. This is estimated to be the effect of stirring of liquid metal by induced current. (Table 2)

Fig. 2 shows the distribution of key component elements analyzed by SEM-EDS near the slag-metal boundary. The slag layer was mainly observed with the slag components Al, etc. The ingot layer was mainly observed with Fe, Cr, etc, components of stainless steel, and Fe was rarely found in the slag layer. Co is relatively low in concentration, so distributions are not clearly visible, but more distributed in the ingot layer.

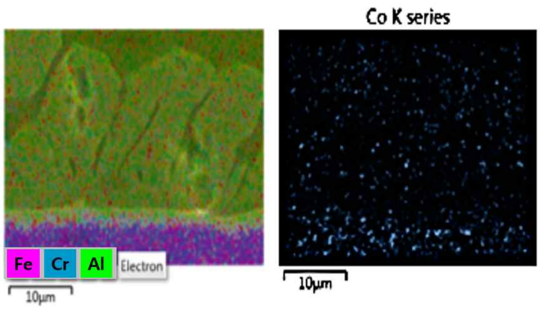

Fig. 2. Distribution of key component elements analyzed by SEM-EDS(Test 2-1)

Table 2: Co concentration of slag and ingot with Fe_2O_3

time (min)	top(ppm)	middle(ppm)	bottom(ppm)	slag(ppm)
0	1808.0	1847.7	1618.4	161.3
20	1594.4	1652.2	1655.4	42.6
40	1709.2	1575.3	1547.8	81.6

2.4 CaF_2 addictive test for Co partitioning in slag

At the beginning of the melting of stainless steel, cobalt mainly stayed at the lower part and showed the large amount distributed to slag. After 20 and 40 minutes and after that, the cobalt was more distributed in the lower part.(Table 3) The slag layer was mainly observed with the slag components Si, Al, etc. The ingot layer was mainly observed with Fe, Cr, etc. Co is relatively low in concentration, so distributions are not clearly visible, but more distributed in the ingot layer which is similar to Fe2O3 addition test. (Fig.3)

Table3: Co concentration of slag and ingot with CaF_2

time (min)	top(ppm)	middle(ppm)	bottom(ppm)	slag(ppm)
0	1778.3	1819.6	2113.2	141.1
20	1857.3	1964.6	2002.4	50.2
40	1921.6	1965.8	1999.8	99.6

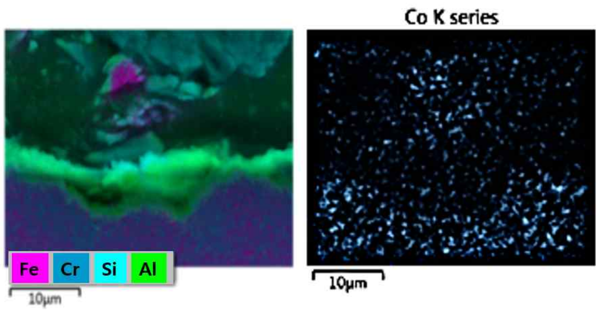

Fig. 3. Distribution of key component elements analyzed by SEM-EDS(Test 2-2)

2.5 MgO addictive test for Co partitioning in slag

At the beginning of the melting of stainless steel, cobalt mainly stayed at the upper part and showed the large amount distributed to slag. Over time, the distribution of cobalt in metal melting does not differ significantly, and slag indicates that a relatively large number of cobalt has been distributed to slag. Cobalt is observed more in slag compare to the other additives addition. (Fig.4)

Table 4 : Co concentration of slag and ingot with MgO

time (min)	top(ppm)	middle(ppm)	bottom(ppm)	slag(ppm)
0	1555.1	1485.9	1441.5	210.5
20	1552.2	1522.0	1580.0	233.2
40	1481.8	1510.3	1404.0	201.4

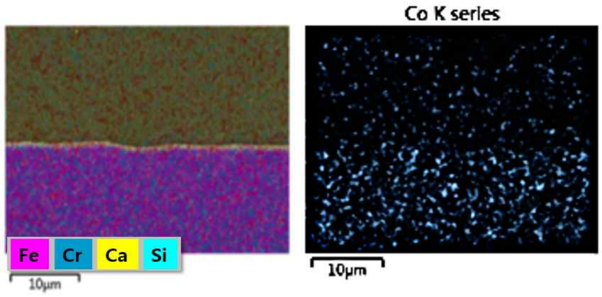

Fig. 4. Distribution of key component elements analyzed by SEM-EDS(Test 2-3)

The slag layer was mainly observed with the slag components Si, Ca, etc. The ingot layer was mainly observed with Fe, Cr, etc.

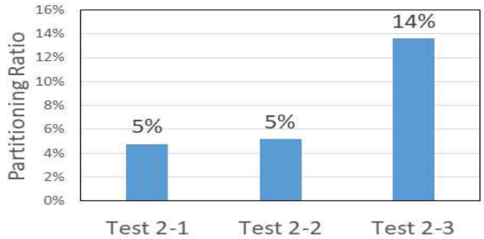

Fig. 5. Co partitioning ratio in slag of stainless steel with different slag composition

The calculation result of distribution ratio according to slag compositions is shown in Fig. 5. When Fe2O3 was added to CaO-SiO2-Al2O3, the base composition of the slag, the distribution ratio of Co is about 5%. The distribution ratio of Co is about 5% when CaF2 was added, which was no significant difference compared to the previous one. But the distribution ratio of Co is about 14% when MgO was added, which was shown the significant effects of Co distribution ratio of slag.

3. Conclusions

The induction melting tests were performed with radioactive stainless steel wastes for volume reduction of metal. The composition effects of the additive in slag were evaluated. The distribution ratio of Co showed about 14% of partitioning ratio in slag with MgO addition. The results will be contributed for recycling and disposal strategies of radioactive metal waste during decommissioning of nuclear power plants.

REFERENCES

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