

SPC-1. Advanced Characterization of Hardfacing Consumable Fume

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Introduction

The study of welding fume has become imperative since medical implications related to welding manufacturing have been realized. The characterization of fume particles in addition to bulk fume using advanced characterization techniques allows for the identification of composition and structure of these purported hazardous materials. In particular, two hardfacing welding consumables and one multipass application consumable were investigated for this study. Fume from gas shielded (100% CO₂) flux-cored wire (TM-771), a self shielded flux-cored wire consumable (Lincore-33), and a shielded metal arc welding consumable (Wearshield-Mangjet) were analyzed. Various collection and characterization techniques were utilized in order to clearly identify the structure and composition of the fume particles.

Procedure

Three consumables were considered for this study: TM-771, Wearshield Mangjet, and Lincore-33. Fume collection was carried out for each respective characterization procedure. Physical distribution measurements were carried out using an electrical low pressure impactor (ELPI). Fume generation rates were conducted using a modified fume hood similar to that described in AWS F1.2:1999. X-Ray Diffraction (XRD) was used to identify compounds contained in the fume. Scanning Electron Microscopy (SEM) was used to analyze fume particles collected from the ELPI in the size range 0.3µm – 10µm. SEM Energy Dispersive Spectroscopy (EDS) was conducted on bulk fume piles as well as individual fume particles and agglomerates. X-Ray Photoelectron Spectroscopy (XPS) was conducted on fume piles collected in the ELPI. Pre and post Ar⁺ ion etching conditions were carried out to determine the change in composition as a result of etch time. Transmission Electron Microscopy (TEM) consisted of analyzing fume particles that were collected above the arc using carbon-copper grids. TEM analysis was conducted on samples that were below 0.3 µm down to approximately 10nm. TEM analysis consisted of using SAD and EDS systems.

Results and Discussion

Fume generation rates for the Lincore-33, TM-771, and Mangjet electrodes were 0.60, 0.77, and 0.83 g/min, respectively. The largest fraction of fume particles for all of the consumables is in the fine and ultrafine regime (less than 1 µm). XRD showed various compounds. All of the fume samples exhibited Fe₃O₄. The XRD results are shown in Table 1.

Table 1. XRD bulk fume analysis results.

	Mangjet	Lincore-33	TM-771
1	Fe ₃ O ₄	MgO	Fe ₃ O ₄
2	Jacobsite **	CaF ₂	MgO
3	FeMn ₂ O ₄	Fe ₃ O ₄	FeO
4	Ti ₃ O ₅	-	NaF

** - (Mn_{0.6}Fe_{0.4})(Mn_{0.4}Fe_{1.6})O₄

↑
Peak Intensity

SEM analysis of the fume particles collected in the ELPI revealed three basic morphologies (spherical, irregular and agglomerated). In addition to those already listed, Lincore-33 exhibited rectangular particles (MgO) interspersed with spherical particles in some of the agglomerates. Mangjet exhibited some core-shell type particles in addition to spherical agglomerates. TM-771 contained large spherical particles that exhibited whisker growth. Average bulk composition data collected using EDS is shown in Table 2. This bulk composition analysis consisted of analyzing the fume piles that were collected on substrates in the ELPI. Individual particles were also analyzed. The composition of these particles/agglomerates had a slightly higher range than that of the bulk composition analyses. An example of one of these individual particles is shown in Figure 1.

Table 2. Average bulk composition of fume piles. EDS analysis at 15-20 kV.

Element	Mangjet		Lincore-33		TM-771	
	Low	High	Low	High	Low	High
Fe	22.1	49.6	6.3	13.6	29.7	76.9
Mn	21.8	48.7	5.6	7.4	4.6	12.1
O	19.4	27.2	22.3	33.4	6.3	38.2
Ca	0.13	0.84	11.1	16.4	0.1	0.36
Mg	0.4	0.6	9.6	15.3	1	6.8
K	0.13	0.22	3.2	6.2	2.7	8.5
Si	0.84	1.1	1.3	2.9	0.98	2.4
F	-	-	5.3	9.3	0.88	5.6
Na	2.1	5.8	-	-	1.5	7.2
S	0.35	4.1	0.2	0.5	-	-
Others	0.21-1.01 Cu		7.9-10.7 Al, 0.67-2.7 Cr, 2.4-3.7 Ba, 1.05 Ti		0.02-0.05 Cl, 0.46-0.66 Zn, 1.25-5.4 Ti	

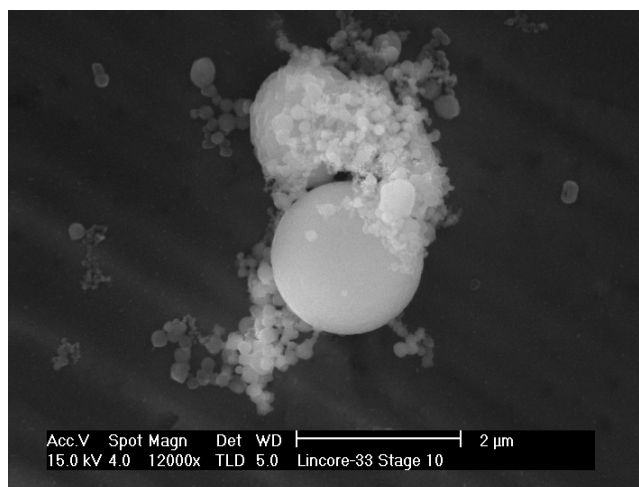


Figure 1. SEM micrograph of large spherical particle with submicron particles attached. Secondary electron image taken at 12,000X. Lincore-33 consumable.

XPS revealed high amounts of light elements on the particle surface in TM-771 (Na, O, C, F, Mg, Fe). Etching resulted in an increase in metallic species concentration in both TM-771 and Mangjet. Light element concentration decreased following etching in both Mangjet and TM-771. Mangjet light elements consisted of Mn, Fe, Na, O, and C. Mn intensity increased by 25% in Mangjet after etching. This supports the fact that a core-shell morphology exists in Mangjet fume particles. The Mn appears to be heavily oxidized. Lincore-33 exhibited high Fe, Ca, Mg, and O concentrations. No variation in Mn content was detected in Lincore-33 fume. The fact that there is not much Mn present in Lincore-33 fume particles is indicative of the low amount of Mn present in the flux.

TEM analysis confirmed XRD results for all the fume types. The majority of fume particles analyzed by selected area diffraction consisted of $(\text{Mn,Fe})_3\text{O}_4$ with varying levels of Mn and Fe in addition to a high Mn-oxide in Mangjet. Lincore-33 also consisted mainly of $(\text{Mn,Fe})_3\text{O}_4$ in addition to MgO. TM-771 also consisted of $(\text{Mn,Fe})_3\text{O}_4$ and MgO in addition to small MgO particles. A TEM image of an $(\text{Mn,Fe})_3\text{O}_4$ particle from a TM-771 fume sample is shown in Figure 2. Other compounds were identified in smaller amounts for Lincore-33. These consisted mainly of Al_2O_3 , SiO_2 , and CaF_2 . Both crystalline and amorphous structures were identified when analyzing the fume particles. Amorphous Si-rich oxides were identified in Mangjet and Lincore-33.

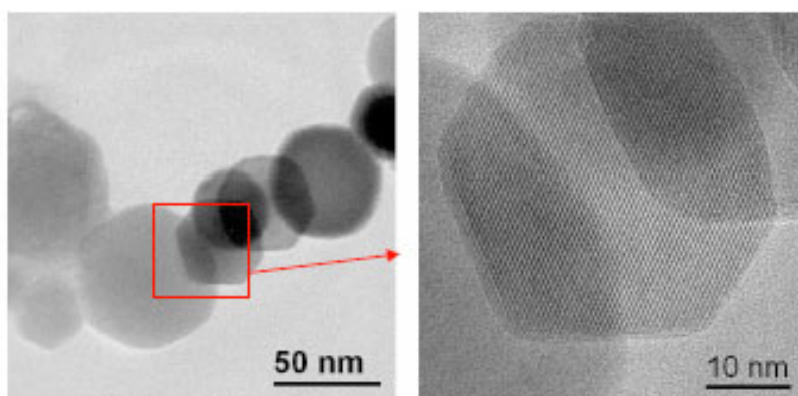


Figure 2. TEM image of $(\text{Mn,Fe})_3\text{O}_4$ particle from TM-771.

Conclusions

Distribution measurements show that the bulk of the fume is concentrated in the fine and ultra-fine regime ($< 1.0\mu\text{m}$). Fume generation rates were around 0.7 ± 0.1 g/min. XRD analysis confirmed the presence of Fe_3O_4 compounds in each of the consumables. TM-771 and Lincore-33 both contained MgO. XPS confirmed the presence of light elements on the surface of fume particles in the pre etch condition. Post Ar^+ ion etching analysis revealed the presence of Fe and Mn within the particle core of Mangjet fume. There was little change in composition between the pre and post etch conditions in Lincore-33. TEM analysis confirmed the presence of $(\text{Mn,Fe})_3\text{O}_4$ in all consumable fumes, and MgO in Lincore-33 and TM-771. The correlation between the characterization processes affirms the presence of select compounds in the fume particles.