DEVELOPMENT OF ENVIRONMENTAL RELEASE ESTIMATES FOR WELDING OPERATIONS

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These metals are reportable under SARA Title III, Section 313, and could be expected from these types of welding operations. Based on the analysis of these samples and the weights of all materials used, emission release factors were developed for fume and slag generated during welding operations. These emission factors can be used to estimate releases to the air and off-site transfers.

TABLE 1. TYPES OF ELECTRODES USED IN FUME TESTS

AWS[a] Class	Type of electrode
E308LSi	Solid electrode
E70S-3	Solid electrode
E70S-6	Solid electrode
E70T-1	Flux-cored electrode
E71T-1	Flux-cored electrode
E6010	Manual
E6011	Manual
E6013	Manual
E308-16	Manual
E7018	Manual

[a] American Welding Society.

The procedures used to develop these data are described in this report. Section 2 describes the sampling procedures. Section 3 presents an overview of the quality of the data generated. Section 4 describes the results of the study. Conclusions are presented in Section 5.

SECTION 4

RESULTS OF WELDING TEST

This section discusses the results of the welding tests and the fate of electrodes during welding. As an electrode is consumed, most of it is deposited onto the base metal. The remainder is either emitted to the air as fume or is deposited onto the weld in the form of slag. Slag is then chipped or brushed from the weld and disposed of as solid waste. The quantity of fume and slag generated for each class of electrode tested is given in Subsections 4.1 and 4.2. Because the steel plates were extremely heavy in comparison with the weight of the weld, the quantity deposited onto the base metal could not be accurately determined; thus, a complete mass balance was infeasible.

4.1 Airborne Emission Results

On the basis of procedures outlined in Section 2 of this report, emission factors were determined for the quantity of fume generated per weight of welding electrode used. Table 5 presents the average weight of fume generated per weight of electrode consumed for the classes of electrodes investigated in this study as well as values extracted from Draft 5 of "Guidelines to Cover SARA Requirements Section 313" (November 20, 1989),[1] denoted as Reference 1.

As shown in Table 5, the weight of fume generated per weight of electrode consumed varied from 0.54 lb/100 lb of electrode for E308LSi to 3.84 lb/100 lb of electrode for E6011. Manual electrodes generally emitted more fume than flux-cored electrodes, which in turn emitted more fume than did solid electrodes.

The experimental values either fell within the range given in Reference 1 or were slightly higher. Experimental values for E308-16, E6010, and E70S-3 electrodes were higher than the range given in Reference 1.

TABLE 5. FUME GENERATED PER AMOUNT OF ELECTRODE USED (lb fume/100 lb electrode consumed)

Electrode class	Type of electrode	Ratio	Reference 1
E70S-3	Solid electrode	0.86	0.20-0.80
E70S-6	Solid electrode	0.79	NA[a]
E308LSi	Solid electrode	0.54	NA
E70T-1	Flux-cored electrode	0.87	0.40-1.1
E71T-1	Flux-cored electrode	1.2	NA
E6010(A)	Manual electrode	2.27	1.0-2.0
E6010(B)	Manual electrode	2.05	1.0-2.0
E6011	Manual electrode	3.84	NA
E6013	Manual electrode	1.36	NA
E308-16	Manual electrode	0.64	0.30-0.60
E7018	Manual electrode	1.57	1.5-2.0

[a] NA = Not available.

Reference 1 did not give details of the welding conditions used. As mentioned in Section 2, all of the tests in this study were performed at the manufacturer's recommended conditions. Detailed operating conditions for each test are given in Appendix B. In all cases, a ½-inch-thick Type A36 steel plate was used for welding.

Shielding gas having a flow rate of 0.67 ft^3/min was used for all flux-cored and solid-wire electrodes. A 98 percent argon/2 percent oxygen mixture was used with Electrode ER308LSi, and carbon dioxide was used with the remainder of the electrodes. A DC600 power supply was used with all of these electrodes. An automatic wire feeder (shown in Figure 2) fed the wire at a constant rate of 275 inches per minute for E308LSi, E70T-1, and E70T-2 electrodes, and 450 inches per minute for E70S-6 and E70S-3 electrodes. The electrode angle was set at a 10-degree lag for all solid-wire and flux-cored welding. The electrical extension (distance between the tip of the electrode and the plate) was set at 3/4 inch for E70S-3, E70S-6, E71T-1, and ER308LSi electrodes and 1 inch for E70T-1. The plate was set to make a weld at a rate of 14 inches per minute. The voltage for all tests was set between 23 and 31 volts, and the current was between 250 and 425 amperes.

A TIG350 power supply (shown in Figure 2) was used with the manual electrodes. Manual electrodes have no electrical extension, but are dragged along the surface of the plate. Although the voltage varies slightly during manual welding, an experienced welder can hold it constant. The voltage read from the power source was watched carefully during each test to ensure it was constant. The voltage for each electrode is given in Appendix B. The current for all of the manual tests was kept constant at the recommended conditions. For all electrodes, the current was in the range of 130 to 180 amps.

These emission factors should suffice for most uses of the studied electrodes. In the event that the welding conditions are vastly different from the manufacturer's recommended conditions, information concerning the effects of operating conditions for different types of electrodes may be obtained from studies compiled in "Fumes and Gases in the Welding Environment." The quantity of fume generated varies directly as a function of the applied voltage and current for all classes of electrodes, though this function may vary for each electrode.[2] Other variables that may impact the quantity of fume generated include the diameter of the electrode, the presence of iron powder, types of shielding gas used, and the presence of fluorides.

For manual (covered) electrodes, the ratio of fume weight to weight of electrode consumed and fume generation rate (FGR) depend on the diameter of the electrode and the composition of the coverings (e.g., presence of iron powder). Fume generation rate (grams per minute) is defined as the amount of fume generated per unit of time. Measured FGRs and ratios of fume weight to weight of electrode consumed for a small-diameter electrode have been found to be less than those of a larger-diameter electrode.[3] It is important to keep in mind that all tests were performed at the manufacturer's recommended conditions. If both small- and large-diameter electrodes are operated at the same conditions (i.e., voltage and current), this would not be the case. Higher voltage and current settings are always recommended for a larger-diameter electrode. If a smaller-diameter electrode were operated at the same current as a larger-diameter electrode, it would have a higher current density (current/unit volume) than the latter electrode. This would then cause the smaller-diameter electrode to generate a higher value for the ratio of fume weight to weight of electrode consumed. The presence of iron powder in the covering of the electrode reduces fume generation rates and the ratio of fume weight to electrode weight consumed.[3]

The fume generation characteristics of flux-cored electrodes are influenced by the diameter of the electrode, the shielding gas used during welding, and the presence of fluorides. If the electrodes are operated at the commercially recommended conditions, as the diameter of flux-cored electrodes is increased, the FGR and ratio of fume weight to electrode weight consumed also increase.[4] Fume generation characteristics can be affected by the type of shielding gas used during welding. An argon-based shielding gas (Ar-XCO_2, where X is an integer) yields lower values for the fume generation characteristics than pure carbon dioxide because the argon-based shielding gas has a lower oxidation potential. Therefore, oxidation processes contributing to fume generation around the tip of the electrode are reduced.[5] Fluorides also may be present in the flux core, which increases fume production.

When electrodes are used at the recommended conditions, fume generation characteristics of solid electrodes depend directly upon the quantity of electrode consumed during welding, as well as the type of shielding gas. The shielding gas has the same effect on solid electrodes as it does for flux-cored electrodes.

Table 6 presents the results of the metals analyses of the welding fume samples. It contains the concentrations expressed in average percent of metal in fume. Laboratory analyses are presented in Appendix C. It should be noted that because the fume was only analyzed for Section 313 metals, the summation of the percentages in Table 6 will not be 100 percent. The remaining percentage will consist primarily of iron with a small amount of silicone.

In general, the composition of the fume generated by manual electrodes reflects the composition of the electrode and the base metal upon which the weld is placed. Estimates of fume compositions could be made for different classes of covered electrodes if the base plate and electrode are matched (electrode is used on the recommended base plate).[6] If this is not the case, fume composition cannot be estimated.

The fume composition of flux-cored electrodes depends on the compositions of the electrode sheath, the flux core, and, to a lesser extent, the base metal. Because the composition of the electrode sheath differs little among manufacturers, variations in the composition of the fume for this type of electrode result from differences in the composition in the flux core.[7] For the purpose of estimating emissions, if no fume composition data are available for a given electrode class, the electrode class that most nearly has the same electrode (flux core) composition should be chosen.

TABLE 6. METAL CONCENTRATION IN FUME OF COMMONLY USED ELECTRODES (percent of total fume)

Electrode class	Aluminum	Barium	Chromium	Cobalt	Copper	Manganese	Nickel	Vanadium	Zinc
E70S-3	0.069	0.011	0.020	0.0017	0.65	6.7	0.0072	0.00076	0.094
E70S-6	0.060	0.0030	0.015	0.0029	0.44	10.4	0.014	0.00099	0.078
E308LSi	0.077	0.0014	6.0	0.0071	0.50	6.4	3.4	0.012	0.042
E70T-1	0.11	0.0018	0.013	0.0022	0.016	9.0	0.0058	0.0045	0.065
E71T-1	0.042	0.0026	0.014	0.0029	0.048	8.1	0.0040	0.0057	0.086
E6010(A)	0.043	0.0012	0.018	0.0023	0.26	3.9	0.026	0.0031	0.022
E6010(B)	0.018	0.00088	0.011	0.0035	0.033	4.4	0.0080	0.0023	0.036
E6011	0.016	0.0012	0.012	0.0025	0.014	2.6	0.014	0.0038	0.016
E6013	0.18	0.00097	0.030	0.0030	0.16	4.1	0.018	0.012	12
E308-16	0.78	0.0062	6.2	0.0078	0.10	3.8	0.82	0.019	0.087
E7018	1.3	0.042	0.024	0.0016	0.072	3.9	0.012	0.00070	0.12

The compositions of the electrode and any coating on the surface of the electrode are the only factors contributing to the composition of the fume generated during the welding with solid electrodes.[8] Thus, fume compositions can be estimated for classes of solid electrodes for which no fume composition data exist.

A comparison was made between the results obtained from these analyses and data in "Fumes and Gases in the Welding Environment"[9] (denoted as Reference 9). A second set of results was extracted from Draft 5 of "Guidelines to Cover SARA Requirements Section 313" (November 20, 1989)[1] (denoted as Reference 1). These results (Table 7) were expressed as percent of metal in fume. In general, the relative percent differences between values generated in this study and those found in Reference 9 are acceptable. Comparison of the values from this study with the range of values found in Reference 1 indicates general agreement on the composition of the welding fume and metal concentrations. No data are available for comparison of some of the fume components.

TABLE 7. PERCENT METAL IN FUME

Electrode class	Metal	This study	Reference 9	Reference 1	RPD[a]
E70S-3	Mn	6.7	5.3	6.5-9.0	23
	Cu	0.65	0.7	0.20-0.60	7.4
E70S-6	Mn	10.4	No data	No data	NA[b]
E308LSi	Mn	6.4	No data	No data	NA
	Cu	3.4	No data	No data	NA
	Cr	6.0	No data	No data	NA
E70T-1	Mn	9.0	9.2	7.5-10.5	2.2
E71T-1	Mn	8.1	No data	No data	NA
E6010(A)	Mn	3.9	3.2	3.0-4.0	20
E6010(B)	Mn	4.4	3.2	3.0-4.0	32
E6011	Mn	2.6	No data	No data	NA
E6013	Mn	4.1	4.9	No data	18
E308-16	Mn	3.8	No data	3.0-4.0	NA
	Cu	0.10	No data	No data	NA
	Cr	6.2	No data	5.5-6.5	NA
	Ni	0.82	No data	0.25-0.75	NA
E7018	Mn	3.9	4.1	3.0-5.0	5.0
	Al	1.3	No data	No data	NA

[a] RPD = Relative percent difference between this study and Reference 9.

[b] NA = Not available.

Average chemical-specific emission factors for the electrode classes studied are presented in Table 8. A chemical-specific emission factor is the estimate of the number of pounds of a particular chemical (in this case, metal) released in the form of fume per a given weight of welding electrode consumed. This factor depends on the class of the welding electrode because it is the product of the ratio of weight of fume generated to weight of electrode consumed and the concentration of the chemical in the fume from that electrode. The values are expressed in units of pounds per ton of electrode consumed and are based on total weight of fume (i.e., weight of fume on glass-fiber filter plus weight of fume on wipe cloth).

TABLE 8. AVERAGE CHEMICAL-SPECIFIC EMISSION FACTORS (FUME)
(pounds of metal in fume per ton of electrode consumed)

Electrode class	Aluminum	Barium	Chromium	Cobalt	Copper	Manganese	Nickel	Vanadium	Zinc
E70S-3	0.012	0.0019	0.0034	0.00029	0.11	1.2	0.0012	0.0013	0.016
E70S-6	0.0094	0.00047	0.0023	0.00045	0.069	1.6	0.0022	0.00015	0.012
E308LSi	0.0083	0.00015	0.65	0.00077	0.054	0.69	0.37	0.0013	0.0045
E70T-1	0.019	0.00034	0.0022	0.00038	0.0028	1.56	0.0010	0.00077	0.011
E71T-1	0.010	0.00062	0.0034	0.00070	0.0012	1.9	0.00096	0.0014	0.021
E6010(A)	0.020	0.00054	0.0082	0.0010	0.12	1.8	0.012	0.0014	0.010
E6010(B)	0.0074	0.00036	0.0045	0.0014	0.014	1.8	0.0033	0.00094	0.015
E6011	0.012	0.00092	0.0092	0.0019	0.011	2.0	0.011	0.0029	0.012
E6013	0.049	0.00026	0.0082	0.00082	0.044	1.1	0.0049	0.0033	3.3
E308-16	0.10	0.00079	0.79	0.0010	0.013	0.49	0.10	0.0024	0.011
E7018	0.41	0.013	0.0075	0.00050	0.023	1.2	0.0038	0.00022	0.038

Table 9 presents the composition of the electrodes according to the material safety data sheets (MSDS). Although aluminum, barium, cobalt, and vanadium are reportable metals under Section 313, none of these metals was listed on the MSDSs. Therefore, they are present at levels below de minimis for each metal and would not be reportable under Section 313. This explains why these metals are present at relatively low levels in the fume. For all of the electrodes except E308-16, manganese is reportable, which explains the higher concentrations of manganese in the fume. The highest chromium and nickel fume concentrations were found in E308LSi and E308-16 electrodes, which were the only electrodes that contained reportable quantities of this metal. The highest zinc levels were found in E6013 and E7018, as expected considering the electrode composition. Although a higher metal concentration in electrodes indicates a higher metal concentration in the fume, no direct relationship appears to exist between the levels in the fume and those in the electrode.

4.2 Slag Release Results

In addition to releases to air during welding operations, many classes of electrodes generate a solid waste (slag) that must also be considered during the development of release estimates under Section 313. Table 10 presents the ratios of the