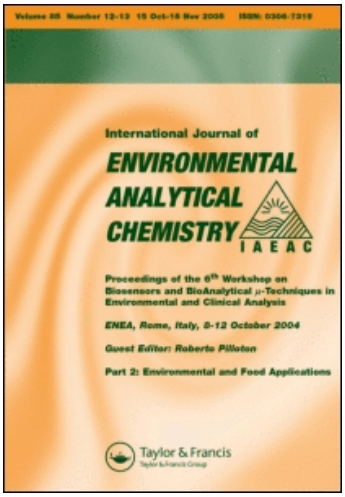

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Particle Emission from Welding of Painted Steel†

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The particulate emission caused by welding of steel plates covered with 29 diversified shop primers has been investigated. The investigation includes the determination of particle mass, particle size distribution, and of the contents of heavy metals such as lead and cadmium. The results show that all investigated primers except those with high concentration of zinc pigment produce mass emissions which are very low in comparison to manual arc welding with covered electrode and CO_2-welding on uncoated steel. The emitted particles of the primers are smaller than 1 μm particle diameter and therefore respirable. Lead and cadmium was found in particles emitted during the welding process of all investigated primers. The highest amount was found in particles of primers with high contents of zinc and ferric oxide.

KEY WORDS: Shop primer, welding, particulate emission, particle size, heavy metal emission

INTRODUCTION

For protection against corrosion steel is covered with shop primers in a layer of about 20 μm. During fabrication the primered steel is welded without removal of the paint. By the high temperatures of welding the paints are decomposed: The organic compounds are cracked while the metals or metal oxides evaporate, followed by oxidation or reduction too. To discuss possible health effects it is necessary to characterize these emissions with respect to the composition of the primer.

In this paper the physical and chemical characterization of the particle emission is reported. The physical characterization is done by measuring

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the particle mass and particle size; the chemical analysis of the particles covers the determination of heavy metals.

EXPERIMENTAL

Welding process and materials

Taking into consideration that only the pollution production by the thermal reaction of the primers should be investigated, the influence of the steel welding process had to be eliminated. This was done by the use of a "neutral" welding process, the Tungsten-Inertgas-Welding without any filler metal. From preliminary tests welding parameters with reproducible particle emissions were chosen. The welding parameters and the characterization of the steel plates are listed in Table I.

TABLE I

Welding process and base material

TUNGSTEN - INERTGAS - WELDING(T I G)	
WELDING CURRENT	I_W = 180 A
WELDING VOLTAGE	U_W = 13 V
WELDING SPEED	V_W = 15 cm/min
INERTGAS FLOW	V_{Ar} = 16 l/min
ELECTRODE DIAMETER	D_E = 3,2 mm
ELECTRODE SPACE	S_E = 3,0 mm
WELDING PERIOD	T = 120 s
BASE MATERIAL	
COLD DRAWN STEEL, C10, WITH ANALYTICAL CERTIFICATE, DIMENSION 350×50×12 mm	

A total of 29 materials were investigated subdivided in three groups:

1) 12 single components of primers (pigments, extenders, and binders).

2) 14 combinations of primer components in given compositions selected in cooperation with manufacturers.

3) 3 commercially available primers.

The detailed composition of these materials is given in Table II. The primers (suspended in organic solvents) were applied to the steel plates with a varnishing machine in layers of $20\,\mu m \pm 3\,\mu m$ thickness. A ten day drying period before welding was essential.

TABLE II

Survey of investigated primers

	NUMBER OF PRIMER	CONTENTS AND QUANTITATIVE RELATION IN [%] PIGMENT	EXTENDER	BINDER
SINGLE COMPONENTS	1	——	——	EPOXY RESIN
	2	——	——	POLYVINYLBUTYRAL
	3	——	——	PHENOLIC RESIN
	4	——	——	ETHYL SILICATE
	5	——	——	ALKYD RESIN
	6	FERRIC OXIDE	——	——
	7	ZINC	——	——
	8	ALUMINUM	——	——
	9	ZINC CHROMATE	——	——
	10	——	BARIUM SULFATE	——
	11	——	MAGNESIUM SILICATE	——
	12	——	CALCIUM CARBONATE	——
COMBINATIONS	13	ZINC (90)	——	EPOXY RESIN (10)
	14	ZINC (90)	——	ETHYL SILICATE (10)
	15	FERRIC OXIDE (70)	——	POLYVINYLBUTYRAL (30)
	16	FERRIC OXIDE (60)	——	PHENOLIC RESIN (40)
	17	FERRIC OXIDE (70)	——	EPOXY RESIN (30)
	18	ALUMINUM (50)	——	EPOXY RESIN (50)
	19	FERRIC OXIDE (60) ZINC CHROMAT (10)	—— ——	EPOXY RESIN (30)
	20	FERRIC OXIDE (70)	——	ALKYD RESIN (30)
	21	FERRIC OXIDE (35)	BARIUM SULFATE (35)	EPOXY RESIN (30)
	22	FERRIC OXIDE (50)	MAGNESIUM SILICATE (20)	EPOXY RESIN (30)
	23	FERRIC OXIDE (35)	CALCIUM CARBONATE (35)	EPOXY RESIN (30)
	24	ZINC (70)	——	EPOXY RESIN (30)
	25	FERRIC OXIDE (50)	——	EPOXY RESIN (50)
	26	FERRIC OXIDE (30)	——	EPOXY RESIN (70)
	27	FERRIC OXIDE (?)		EPOXY RESIN (?)
	28	ZINC (?)		EPOXY RESIN (?)
	29	FERRIC OXIDE (?)		DESMODUR E 1375 (?)

Test setup and methods of investigation

The painted steel plates were fixed on a welding table of an automatic welding machine. The TIG-burner with a fitted stainless steel exhaust hood was moved with the given velocity across the primered plate (Figure 1). The whole particle mass during every welding period was collected by means of a glass fibre filter (Sartorius SM 134) mounted in the top of the hood. The volume drawn by the exhaust fan was 1300 l/min with a pressure drop of approximately 0.07 bar, which didn't change during collecting regardless of the use of high zinc pigmented primers.

The particle mass emission was determined gravimetrically by use of a microbalance. Every filter was dried before weighing for 30 min at 60°C which was the highest temperature the filters were exposed to during welding. Afterwards the filters were sealed and stored for chemical analysis. The determination of the contents of heavy metals in the

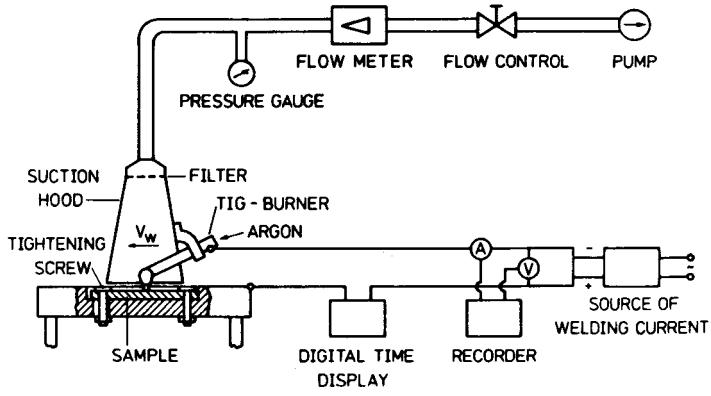

FIGURE 1 Test Setup.

particles was done by use of atomic absorption spectrometry (Rank Hilger, H 1550 with carbon rod atomizer H 1475). The weighed filters were cut into representative parts and extracted by mineral acids. Filter samples were treated with 0.1 n HNO_3 or HCl by use of ultrasonic vibrations to dissolve lead, cadmium, and zinc compounds.[1,2] In the case of metal oxides which were difficult to dissolve the filter pieces were digested with a mixture of hot mineral acids in a Teflon beaker.[3] The elements lead and cadmium present in low concentrations were determined by flameless AA, while the other metals have been measured in an Acetylene/air-flame. Background correction was achieved by use of a continuous lamp and the method of standard addition.

The particle size distribution of the emission was determined with an electrical aerosol analyzer ("EAA", TSI Type 3030). For measuring particle size the test setup was changed: A sampling device with a 19 mm diameter tube was mounted in the middle of the hood at the same height as the filter used for mass collection. The sampling tube, operated at isokinetic flow conditions, drew a representative sample of the particles out of the main stream and lead it through a cartridge filter diluter to the EAA.[4] The measuring range of the EAA covers a particle size range between 0.01–1 μm particle diameter. The instrument determines the particle number concentration in 8 particle size classes.[5,6]

RESULTS

Three determinations of mass emission were performed for every primer listed in Table II and after taking the mean the appropriate particle mass flows were calculated (Figure 2). Additionally the particulate emission of

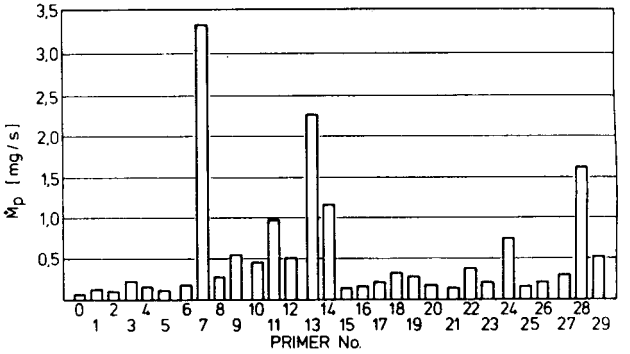

FIGURE 2 Particle mass flows of the primers.

an uncoated plate (No. 00, Figure. 2) and the background mass concentration of the ambient air used for transport and dilution were determined ($\dot{m}_p = 0.003$ mg/s). The mass emissions of primers with zinc pigment (s. No. 7, 24, 28 in Figure 2) are much higher than for all other investigated primers, but their emissions reach only the range of those produced by typical manual electrode welding[7] and CO_2-welding[8] of uncoated steel.

The particulate matter of all primer components and the commercial primers collected on filters was analyzed for content of lead and cadmium (Table III). The contents of zinc and iron were determined only for some chosen primers, because these results could be transferred to the zinc and

TABLE III

Contents of heavy metals in the particles

No	PRIMER	LEAD		CADMIUM		ZINC		IRON	
		$\bar{x}$(µg/g)	µg/s	$\bar{x}$(µg/g)	ng/s	$\bar{x}$(%)	mg/s	$\bar{x}$(%)	µg/s
1	EPOXY RESIN	1852	0,245	31	4	—	—	—	—
2	POLYVINYLBUTYRAL	1632	0,189	21	2	—	—	—	—
3	PHENOLIC RESIN	744	0,165	18	4	—	—	—	—
4	ETHYL SILICATE	2042	0,235	26	3	—	—	—	—
5	ALKYD RESIN	1092	0,138	18	2	—	—	—	—
6	FERRIC OXIDE	3380	0,538	39	6	—	—	65,9	105
7	ZINC	417	1,42	76	280	76,9	2,58	—	—
9	ZINC CHROMATE	1599	0,73	41	17	—	—	—	—
10	BARIUM SULFATE	392	0,141	6	2	—	—	—	—
11	MAGNESIUM SILICATE	259	0,492	16	15	—	—	—	—
12	CALCIUM CARBONATE	344	0,139	5	2	—	—	—	—
19	FERRIC OXIDE, ZINC CHROMATE, EPOXY RESIN	—	—	—	—	56,6	0,10	—	—
24	ZINC, EPOXY RESIN	—	—	—	—	65,1	0,44	—	—
27	FERRIC OXIDE, EPOXY RESIN,?	3883	0,942	60	15	4,50	0,01	19,5	51
28	ZINC, EPOXY RESIN,?	441	0,80	110	200	73,2	1,33	—	—
29	FERRIC OXIDE, DESMODUR,?	960	0,610	14	9	—	—	—	—
00	UNCOATED STEEL	1836	0,08	16	0,8	2,5	0,001	51,2	22

iron contents of the other primers. In addition to the concentration data the calculated metal mass flows, that is the mass emission of a metal per time unit, are given in Table III, because these data permit a comparative and mutual evaluation of the primers' emissions. Blank values were also determined and taken into account in the measured values, which are mean values of three independent determinations. The particles emitted from welding of uncoated steel were investigated too.

The analyzed metals are in oxidized form, but their real structure is complex and has not been researched here. The results in Table III show that the lead and cadmium emissions of most primers are low.

Zinc and ferric oxides produce the highest amount of lead and in the case of zinc primers cadmium, too. For zinc pigmented primers most of the emission consists of oxidized zinc caused by its high volatility. To get some more information about the composition of unknown primers and the alteration of the concentrations of certain heavy metals in original primers and emitted particles, several paints have been analyzed (Table IV). The results reveal as expected that the concentrations of the volatile metals like zinc, cadmium, and lead increase in the emitted particles.

TABLE IV
Contents of heavy metals in the applied primers

No.	PRIMER	LEAD[ppm]	CADMIUM[ppm]	IRON[%]	ZINC[%]	CHROMIUM[%]
6	FERRIC OXIDE	136	1,4	69,2	—	—
7	ZINC	437	32,0	—	—	—
8	ALUMINUM	4	0,06	—	—	—
9	ZINC CHROMATE	550	17,0	—	—	—
27	COMMERCIAL	489	3,3	29,7	1,6	0,89
28	COMMERCIAL	402	86,0	—	76,9	—

By the evaluation of the EAA data particle number distributions were obtained which are plotted for some typical primers in Figures 3 and 4. All measured distributions are similar in shape and height except the distribution obtained from welding over uncoated steel which indicates that the coatings lead to increased particle number concentrations in the particle diameter range above 0.3 μm. Nearly all emitted particles are smaller than 1.0 μm and therefore respirable. As health effects are probably determined by the mass of the pollutants, statements in regard to the mass such as particle volume distributions were calculated under assumption of spherical particles and plotted in Figures 5 and 6 for the corresponding primers. These representations indicate that the mass mean diameter of the emitted particles is around 0.1 μm.

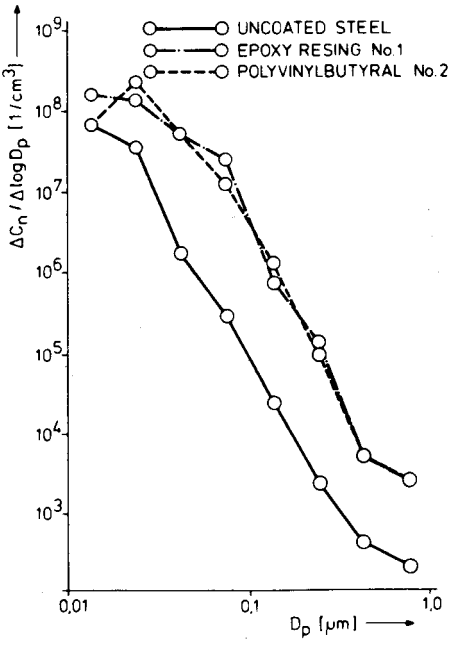

FIGURE 3 Particle number distributions.

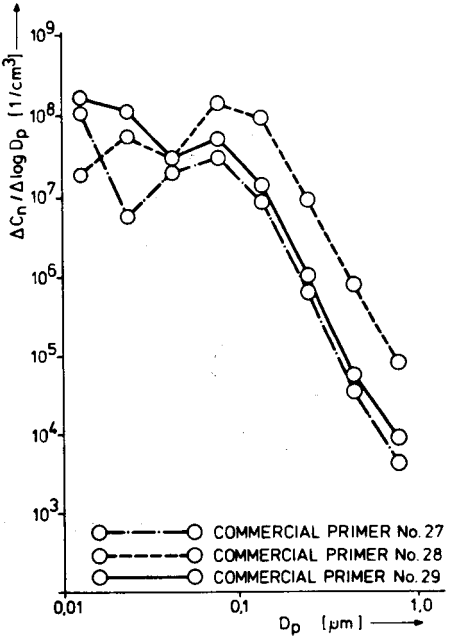

FIGURE 4 Particle number distributions.

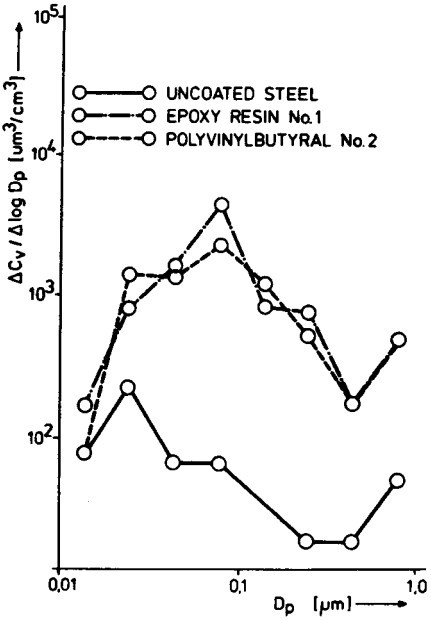

FIGURE 5 Particle volume distributions.

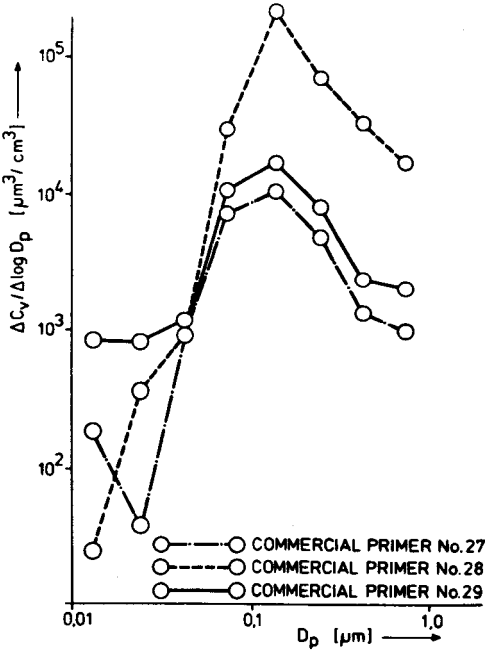

FIGURE 6 Particle volume distributions.

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