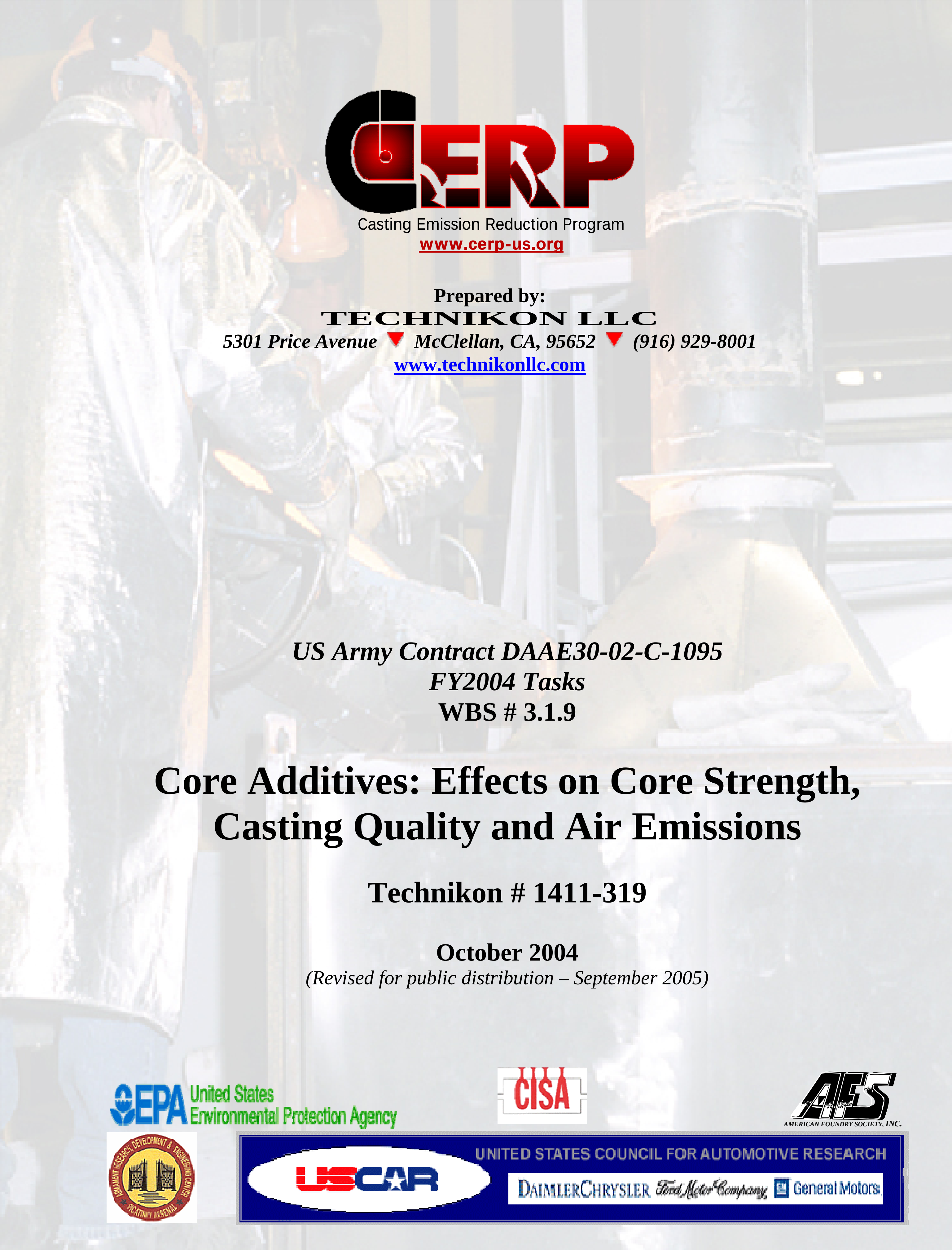

CERP
Casting Emission Reduction Program
www.cerp-us.org

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Core Additives: Effects on Core Strength, Casting Quality and Air Emissions

Technikon # 1411-319

October 2004
(Revised for public distribution – September 2005)

EPA United States Environmental Protection Agency

CISA

AFS AMERICAN FOUNDRY SOCIETY, INC.

USCAR UNITED STATES COUNCIL FOR AUTOMOTIVE RESEARCH
DaimlerChrysler Ford Motor Company General Motors

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Core Additives: Effects on Core Strength, Casting Quality and Air Emissions

Technikon # 1411-319

AFS Paper 05-129

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1.0 Abstract

Work being conducted at the Casting Emission Reduction Program (CERP), led to the question: "What effect do additives have on the total process emissions"? To answer this question, the (CERP) group completed a study that looked at four commonly used core additives (Red Iron Oxide, Black Iron Oxide, aluminum silicate (Veino®), and blended materials (Macor®) and their effects on emissions, core tensile strength and casting quality. Core casting surface finish and air emissions data were collected for cores produced with batches of sand containing 1.4% Phenolic Urethane cold box binder and selected additives. This study also documented the tensile strength changes at various binder levels for each anti-veining additive and developed an algorithm to predict the additional binder required to maintain mechanical properties. The testing indicated that the resultant emissions were quite varied with respect to the different additives. A 2% Black Iron Oxide addition increased emissions, measured as TGOC, by approximately 2%. The blended material, added at a 1.5% rate, showed a 1% decrease in emissions. A 5% aluminum silicate addition showed an emissions decrease of 25%, and a 1% Red Iron Oxide addition generated an 8% decrease in emissions. With the additives exhibiting an ability to effect emissions, both the potential for additional binder needed to maintain core properties and the effect of the additive on the total emissions needs to be taken into consideration when selecting an additive package for a given binder/sand system.

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2.0 Introduction

Sand additives have been used in the foundry industry for many years. While working on other projects aimed at defining the emission characteristics of foundry products, the effect of core additives, when used in conjunction with these products, was questioned. It has been well documented that the use of additives is necessary to reduce veining in some casting applications. The contribution of the additives themselves to the emissions was not understood. The Casting Emission Reduction Program (CERP) was asked to investigate the effect of additives on system emissions. To fully address this issue, it was necessary to look at the emission potential of the additives as well as the effect of the additional resin needed to maintain core mechanical properties. This report documents the methodology and results of testing conducted to evaluate the impact of anti-veining compound additions on core formulations. These tests focused on the impact these core additives had on emissions, tensile strength, and casting quality. The report is divided into three (3) sections. The first section discusses air emission testing results. The second section discusses the impact on core tensile strength, and the third section examines the casting quality results.

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3.0 Testing Approach

Testing consisted of two activities. Green sand molds containing the cores with various anti-veining compounds were poured with iron at 2630°F to assess the effect of the different additives on emissions. The castings produced were visually examined on the core surfaces to assess surface finish and appearance. Concurrently, core tensile specimens (dogbones) were produced from the core sand mixtures to assess the impact of the additive packages on the resultant core strengths. Only 24 hour tensile strengths values were taken. .

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4.0 Section 1: Emissions testing

The testing was conducted to evaluate four (4) different anti-veining additives: red iron oxide at 1%, black iron oxide at 2%, aluminum silicate (Veino®) at 5% and a blended material (Macor®) at 1.5%. These compounds were selected since they represent the four main categories of additives typically utilized by the foundry industry. All testing was conducted by Technikon, LLC in its research foundry for the Casting Emission Reduction Program (CERP). The emission results are reported in both pounds of analyte per pound of binder, and pounds of analyte per ton of metal poured. These tests were conducted using a phenolic urethane cold box core binder at 1.4% based on sand weight (BOS). While it is recognized that binder content is typically adjusted in a production situation to compensate for reductions in core tensile strength, the resin content was maintained at 1.4% to maintain comparability.

4.1 METHODOLOGY

The testing performed involved the collection of continuous air samples over a seventy-five minute period, including the mold pouring, cooling, shakeout, and post shakeout periods. Process and stack parameters were identified and measured as shown in Table 1. The process parameters were maintained within prescribed ranges in order to ensure the reproducibility of the test runs. Samples were collected and analyzed for sixty-eight target compounds using procedures based on US EPA Method 18. Continuous monitoring of the Total Gaseous Organic Concentration (TGOC) of the emissions was conducted according to US EPA Method 25A. Table 1 provides a summary of the test plan. Figures 1 through 3 illustrate equipment used.

Table 1 Test Plan Summary

	Test Plans
Type of Process Tested	Phenolic Urethane Core Binder with Anti-Veining Compounds, Greensand without Seacoal, Iron Pouring, Cooling, and Shakeout.
CERP Test Plan Number	1410 114 FR , 1410 115 FT, 1411 610 FX & GF*
Greensand System	Wexford W450 Lakesand, Western and Southern Bentonite in a 5:2 ratio, No Seacoal
Metal Poured	Class 30 Iron, 2630°F
Casting Type	4-on Step Core
Core Binder	1.4% Ashland ISOCURE® 305/904
Core Sand	Amador A-70 Silica Sand
Anti-Veining Materials	No Addition 1% Red Iron Oxide, 2% Black Iron Oxide 5% (BOS) Aluminum Silicate (Ashland 050360 Veino®) 1.5 % (BOS) Blended Material (J.S. McCormick Co. Macor® 1032)
Number of Molds Poured	For each Configuration: 3 Conditioning and 4 Sampling (Total of 35 Molds)
Test Dates	3/30/04 > 4/8/04 and 1/15/04 >1/21/04
Emissions Measured	TGOC as Propane, HC as Hexane, 68 Target Analytes (Organic HAPs and VOCs)
Process Parameters Measured	Total Casting, Mold Binder, Core Binder, and Anti-veining compound weights; Metallurgical data, % LOI; Stack Temperature, Moisture Content, Sand Temperature, Pressure, and Volumetric Flow Rate

* Complete text of these tests may be found at www.cerp-us.org.

4.2 MOLD, CORE AND METAL PREPARATION

The molds and cores were prepared to a standard composition by the Technikon production team. The step cores used for this evaluation were mixed in a Klein vibratory mixer and blown in a Redford/Carver core machine. A green sand mixture containing no carbon additives was produced for the test molds. Molds were produced using an Osborn hydraulic squeeze molding unit. Relevant process data were collected and recorded. Iron was melted in a 1000 lb. Ajax induction furnace. The amount of metal melted was determined from the poured weight of the casting and the number of molds to be poured. The metal composition was Class-30 Gray Iron as prescribed by a metal composition worksheet. The weight of metal poured into each mold was recorded on a process data summary sheet. Figures 1 through 3 illustrate equipment used to conduct the tests.

Figure 1 Step Core Machine

Figure 2 Emission Test Enclosure

4.3 SAMPLING

Replicate test runs were performed on twenty (20) molds after conditioning in five groups of four molds each. An individual green sand mold, containing four step cores, was placed into an enclosed test hood that was heated to approximately 85°F. Iron was poured into the mold through an opening in the top of the emission test enclosure; after pouring was completed, the opening was closed. The emission test enclosure meets the US EPA Method 204 criteria as a total enclosure even

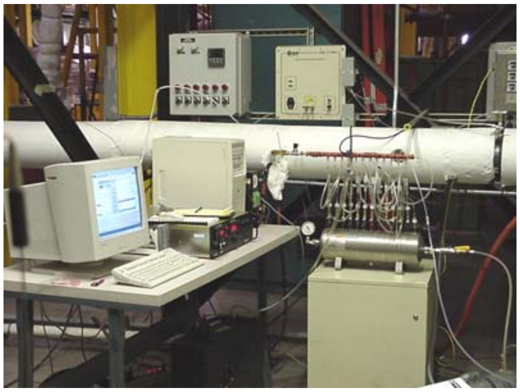

Figure 3 Method 25A (TGOC) and Method 18 Sampling Train

during the pouring event. Continuous air samples were collected during the forty-five minute pouring and cooling process, the fifteen minute mold shakeout period, and for an additional fifteen minutes following shakeout. The total sampling time was seventy-five minutes.

4.4 EMISSION TESTING

Tables 2 and 3 present the five emission indicators and selected individual VOC and HAP emissions.

Table 2 Summary of Test Average Results – Lb/Lb Binder

Analytes	Baseline W/O Additives (Lb/Lb Binder)	Red Iron Oxide (Lb/Lb Binder)	Red Iron Oxide % Change from Baseline	Black Iron Oxide (Lb/Lb Binder)	Black Iron Oxide % Change from Baseline	Aluminum Silicate (Veino®) (Lb/Lb Binder)	Aluminum Silicate (Veino®) % Change from Baseline	Blended Material (Macor®) (Lb/Lb Binder)	Blended Material (Macor®) % Change from Baseline
TGOC as Propane	0.148	0.1366	-8	0.151	2	0.1117	-25	0.1466	-1
HC as Hexane	0.0482	0.0421	-13	0.0498	3	0.0328	-32	0.0416	-14
Sum of TA	0.0591	0.0536	-9	0.0645	9	0.0452	-23	0.0497	-16
Sum of HAPs	0.0554	0.05	-10	0.0602	9	0.0425	-23	0.0453	-18
Sum of POMs	0.0169	0.0159	-6	0.0192	14	0.0119	-29	0.0148	-12
Individual Organic HAPs									
Benzene	0.0174	0.0132	-24	0.0156	-10	0.0138	-21	0.0127	-27
Phenol	0.0113	0.0118	5	0.0142	26	0.0083	-27	0.0081	-28
Methylnaphthalenes	0.0085	0.0086	2	0.0106	24	0.0063	-26	0.008	-6
Naphthalene	0.0062	0.0051	-18	0.0061	-2	0.0039	-37	0.0047	-24
o,m,p-Cresol	0.003	0.0024	-19	0.0034	15	0.0024	-19	0.0021	-28
Toluene	0.0026	0.0024	-7	0.0029	12	0.0024	-6	0.0032	25
Dimethylnaphthalenes	0.0022	0.0022	0	0.0026	19	0.0018	-18	0.0022	-1
Aniline	0.0021	0.0022	4	0.0023	10	0.0012	-44	ND	NA
o,m,p-Xylene	0.001	0.001	0	0.0012	17	0.0011	8	0.0013	29
Acetaldehyde	0.0005	0.0006	7	0.0006	7	0.0006	12	0.0018	228
Hexane	0.0001	0.0001	0	0.0001	0	0.0001	0	0.0004	309
Other VOCs									
Trimethylbenzenes	0.0013	0.0013	0	0.0016	28	0.0006	-49	0.0012	-2
Ethyltoluenes	0.0005	0.0005	0	0.0006	28	0.0003	-37	0.0004	-12
Octane	ND	ND	NA	ND	NA	0.0011	NA	0.0012	NA

Individual results constitute >95% of mass of all detected VOCs.

ND: Non Detect; NA: Not Applicable

All "Other Analytes" are not included in the Target Analytes (TA) or HAPs.

Table 3 Summary of Average Test Results – Lb/Tn Metal

Analytes	Baseline W/O Additives (Lb/Tn Metal)	Red Iron Oxide (Lb/Tn Metal)	Red Iron Oxide % Change from Baseline	Black Iron Oxide (Lb/Tn Metal)	Black Iron Oxide % Change from Baseline	Alunimum Silicate (Veino®)(Lb/Tn Metal)	Alunimum Silicate (Veino®) % Change from Baseline	Blended Material (Macor®) (Lb/Tn Metal)	Blended Material (Macor®) % Change from Baseline
TGOC as Propane	0.9259	0.83	-10	0.9706	5	0.7116	-23	0.9177	-1
HC as Hexane	0.3016	0.2555	-15	0.3198	6	0.2088	-31	0.2606	-14
Sum of TA	0.3705	0.3264	-12	0.4162	12	0.2909	-21	0.3111	-16
Sum of HAPs	0.3474	0.3074	-12	0.3886	12	0.2732	-21	0.2838	-18
Sum of POMs	0.1059	0.0966	-9	0.1241	17	0.0763	-28	0.0928	-12
Individual Organic HAPs									
Benzene	0.1088	0.08	-26	0.101	-7	0.0884	-19	0.0793	-27
Phenol	0.0707	0.0719	2	0.092	30	0.0527	-25	0.0506	-28
Methylnaphthalenes	0.0533	0.0525	-2	0.0681	28	0.0401	-25	0.0498	-6
Naphthalene	0.0389	0.031	-20	0.0392	1	0.0248	-36	0.0294	-24
o,m,p-Cresol	0.0187	0.0154	-18	0.0222	19	0.0154	-17	0.0134	-28
Toluene	0.0161	0.0144	-10	0.0186	16	0.0153	-4	0.02	25
Dimethylnaphthalenes	0.0185	0.0188	2	0.0169	-9	0.0114	-38	0.0136	-26
Aniline	0.013	0.0132	2	0.0147	13	0.0073	-43	ND	NA
o,m,p-Xylene	0.0064	0.0059	-7	0.0077	20	0.007	10	0.0082	29
Acetaldehyde	0.0034	0.0035	4	0.0039	14	0.0049	44	0.0112	228
Hexane	0.0006	0.0005	-16	0.0008	33	0.0009	56	0.0024	309
Other VOCs									
Trimethylbenzenes	0.0079	0.0077	-3	0.0104	32	0.0041	-48	0.0077	-2
Ethyltoluenes	0.0028	0.0028	0	0.0037	31	0.0018	-36	0.0025	-12
Octane	ND	ND	NA	ND	NA	0.0069	NA	0.0072	NA

Individual results constitute >95% of mass of all detected VOCs.

ND: Non Detect; NA: Not Applicable

All "Other Analytes" are not included in the Sum of Target Analytes (TA) or HAPs.

Figures 4 and 5 present the five emissions indicators and selected individual HAP and VOC emissions data from Tables 2 & 3 in graphical form based on binder weight & cast metal weight respectively.

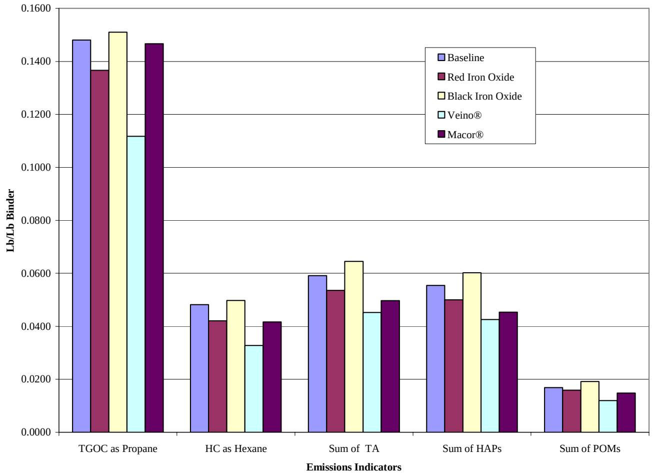

Figure 4 Emission Indicators from Test Series FT – Lb/Lb Binder

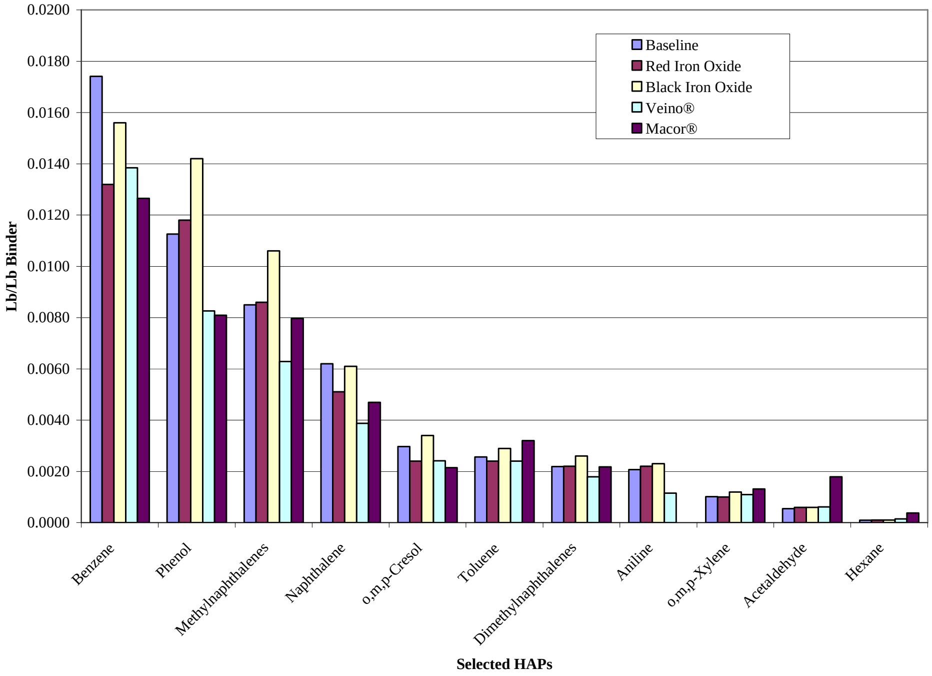

Figure 5 Selected HAP Emissions from Test Series FT– Lb/Lb Binder

Two methods were employed to measure undifferentiated hydrocarbon emissions: TGOC as propane, performed in accordance with EPA Method 25A, and HC as hexane, a WCMA method. EPA Method 25A, TGOC (as propane), is weighted to the detection of more volatile hydrocarbon species, beginning at C1 (methane), with results calibrated against a three-carbon alkane (propane). HC as hexane is weighted to the detection of relatively less volatile compounds. This method detects hydrocarbon compounds in the alkane range between hexane (C6) and hexadecane (C16), with results calibrated against a six-carbon alkane (hexane).

An independent test for volatile matter content based on EPA Method 24 was performed to determine the amount of available VOCs in the binder system used for this test.

Table 4 includes the averages of the key process parameters measured during the emissions testing.

Table 4 Summary of Test Plan for FR and FT Average Process Parameters

Greensand PCS with Anti-Veining Core Additive					
Test FT and FR	**Reference No additions**	**Red Iron Oxide**	**Black Iron Oxide**	**Aluminum Silicate (Veino®)**	**Blended Material (Macor®)**
Test Dates	1/15-16/04	1/21-21/04	1/28-29/04	3/30-31/04	4/5-7/04
Cast weight (all metal inside mold), Lbs.	111.1	111.5	109.3	109.8	110.5
Pouring time, sec.	28	24	21	19	21
Pouring temp ,°F	2632	2630	2630	2629	2634
Pour hood process air temp at start of pour, °F	87	87	87	89	88
Mixer auto dispensed batch weight, Lbs	45.35	42.9	45.67	44.9	44.91
Calibrated auto dispensed binder weight, Lbs	0.633	0.6	0.634	0.625	0.627
Core binder calibrated weight, %BOS	1.39	1.4	1.39	1.39	1.4
Core binder calibrated weight, %	1.38	1.38	1.37	1.37	1.38
Total uncoated core weight in mold, Lbs.	25.25	24.55	25.66	25.46	25.15
Total binder weight in mold, Lbs.	0.347	0.339	0.351	0.35	0.346
Core LOI, %	1.26	1.34	1.38	1.27	2.22
Core dogbone 2 hour tensile, psi	40	NA	50.2	30	31
Core age, hours	61	61	62	107	60
Muller batch weight, Lbs.	900	900	900	900	900
GS mold sand weight, Lbs.	620	612	597	609	615
Mold compactability, %	56	55	57	51	52
Mold temperature, °F	70	67	67	73	71
Average green compression , psi	11	14	17.3	15.13	17.4
GS compactability, %	53	51	50	38	42
GS moisture content, %	2.27	2.3	2.41	1.84	2.09
GS MB clay content, %	6.02	6.02	7.34	8.1	7.63
MB clay reagent, ml	26	25.8	31.4	32.4	30.5
1800°F LOI - mold sand, %	0.71	0.81	0.86	1.03	0.99
900°F volatiles , %	0.24	0.28	0.25	0.44	0.47

4.5 DISCUSSION OF EMISSIONS TEST RESULTS

The following tables and charts show that the aluminum silicate is the only additive to have a statistically significant effect on the overall emissions measured based on the five (5) emissions indicators (TGOC, HC as Hexane, and the Sums of target analytes (TA), HAPs and POMs). As expected, benzene, phenol, and components of the phenolic urethane solvent system are the most abundant of the target analytes. Finally, due to the constituents in the blended material (Macor®); there was an increase in the acetaldehyde emissions for that additive test.

The change in the emissions with additives relative to the baseline without an additive was measured only at 1.4 % binder. Previous testing at CERP has shown that emissions are directly proportional to the core binder level. The following section of this paper presents the work conducted to obtain the relationship between binder level and mechanical strength. Table 10 combines this information and shows the estimated TGOC emissions that would be expected if the amount of binder were adjusted to obtain a mechanical strength equivalent to that of the baseline system.

5.0 Section 2 Tensile Strength Testing

The objective of this testing was to determine how much additional cold box binder would be required to compensate for tensile strength loss due to the addition of the anti–veining compounds. While the binder level was held at 1.4% for the emissions assessment, it was recognized that some additive types tend to adversely affect the mechanical properties of the core. Since most foundries will increase binder levels to obtain satisfactory mechanical properties, it was felt by the authors that this needed to be documented. Earlier research conducted at CERP has demonstrated that the effect of binder percentage on emissions is linearly proportional. Once the effect of the additives is understood, it is fairly straightforward to assess the total impact on emissions by correcting for the additional resin needed to maintain core mechanical properties.

5.1 METHODOLOGY

The testing was conducted in the Technikon foundry core room and materials laboratory using methods based on the AFS Mold & Core Testing manual 3rd addition. Wedron 530 silica sand was used as the base sand for this test series. Batches were produced using phenolic urethane cold box binder at 1.10%, 1.40%, & 1.75 % addition levels (BOS). Core sand additives were included in specific batches as indicated in Table 5. .A Hobart laboratory mixer was utilized to produce the batches of sand needed for the tests. All sand batches were mixed for 4 minutes at 72 ^{o}F to ^{o}F (Figure 6). A Redford-Carver core blower (Figure 1) was used to produce all tensile cores; triethylamine (TEA) was used as the catalyst. In all, 16 groups of 30 cores each were produced; 15 groups for the test series and an additional group with no additives. The cores were identified with the batch number of the mix, the blow cycle within the batch, and the core box cavity number. All cores were held for 24 hrs before being broken on a Thwing-Albert tensile tester. A summary of the test plan process parameters are shown in Tables 5 and 6. Tools and equipment used are shown in Figures 6 to 11.

Table 5 Number of Dogbone Tensile Test Pieces to be Made from the Compositions Listed

Additions	1.1% Binder BOS	1.4% Binder BOS	1.75% BOS
No Additions	30	30	30
1% Ashland Red Iron Fine Oxide	30	30	30
2% Chesapeake Specialties SpherOX Fine Black Oxide	30	30	30
1.5% Blended Material (Macor®)	30	30	30
5% Aluminum Silicate (Veino®)	30	30	30

Table 6 Process Parameters Measured

Parameter	Analytical Equipment and Methods
Core weight	Mettler SB12001 electronic platform scale (gravimetric)
Sand Temperature	Fluke 52 thermocouple
LOI	Denver analytic (AFS procedure 5100-00-S)
Sand batching weight	Mettler SB12001 electronic platform scale (gravimetric)
Core machine pressure	Machine mounted pressure gauge
TEA gas & purge air temperature	Chromolox temperature controller
Tensile tester ambient temperature	Room ambient air temperature control system

Figure 6 Hobart Epicentric Sand Mixer

Figure 7 Redford/Carver Dogbone Core Machine

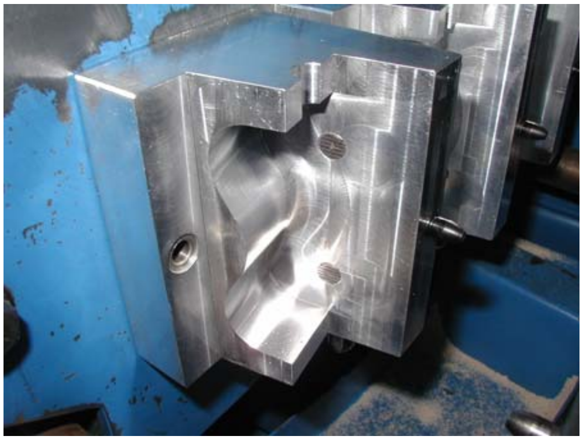

Figure 8 Three-on Dogbone Core Box

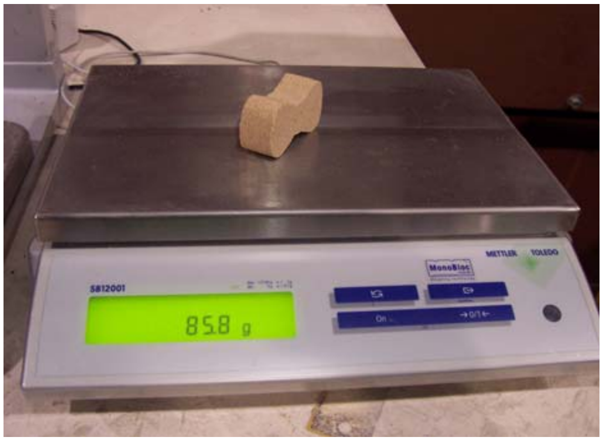

Figure 9 Weighing Dogbones to 0.1 Gram Resolution

Figure 10 Thwing-Albert QC-3A Tensile Tester

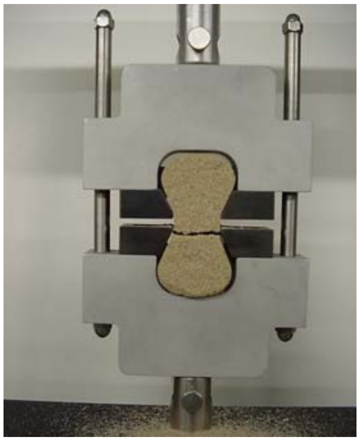

Figure 11 Tested Dogbones

5.2 DISCUSSION OF TENSILE STRENGTH TEST RESULTS

Tensile strength was nearly linear with binder concentration in the range investigated for all materials. As is typically observed in the field, black iron oxide had the least effect on tensile strength. This was followed by red iron oxide, aluminum silicate and the blended material. Based on the 1.4 % binder data in Table 7, the loss in tensile strength averaged 22% for red iron oxide, 14% for black iron oxide, 53% for blended material, and 25% for aluminum silicate. A regression analysis was completed on the data (see Table 8). The equations predicted that the binder would need to be increased by 16% for red iron oxide, 7% for black iron oxide, 64% for blended material, and 23% for aluminum silicate. Comparing these two calculations, it appears that the results are consistent. It should be noted that the algorithm developed in Table 8 is only valid in the 1.1% to 1.75 binder range and is only valid for the sand and phenolic urethane binder system used in these experiments.

While these values are not atypical for systems using additives, the important factor in this study is to demonstrate the potential increase in emissions due to the necessity to increase the binder level to maintain the mechanical properties of the cores. This point will be discussed later in the paper.

Average tensile strength vs. binder content for core containing various anti-veining compounds is shown in Table 7.

Table 7 Average Tensile Strength of 30 Dogbones for Each Composition

Binder Content, % BOS	1.1%	1.4%	1.75%
Anti-Vein Addition	**Tensile Strength, psi**		
No Addition	206.6	301.2	355.4
1% Red Iron Oxide	165.8	233.7	310.4
2% Black Iron Oxide	191.7	259.6	337.5
1.5% Blended Material (Macor®)	87.8	142.9	192.5
5 % Aluminum Silicate (Veino®)	156.1	226.5	288.3

Table 8 Regression Equations to Determine the Equivalent Amount of Binder Required to Offset the Effects of Adding Anti-Veining Compound

Anti-Veining Addition	Binder Required to Achieve Equal Tensile Strength	Equivalent Binder Level Computed to 1.4% Baseline Strength
1% Red Iron Oxide	C = 1.02 * C (no addition) + 0.20	1.02 * 1.4 + 0.20 = 1.63%
2% Black Iron Oxide	C = 1.01 * C (no addition) + 0.09	1.01 * 1.4 + 0.09 = 1.50%
1.5% Blended Material	C = 1.41 * C (no addition) + 0.33	1.41 * 1.4 + 0.33 = 2.30%
5% Aluminum Silicate	C = 1.12 * C (no addition) + 0.15	1.12 * 1.4 + 0.15 = 1.72%

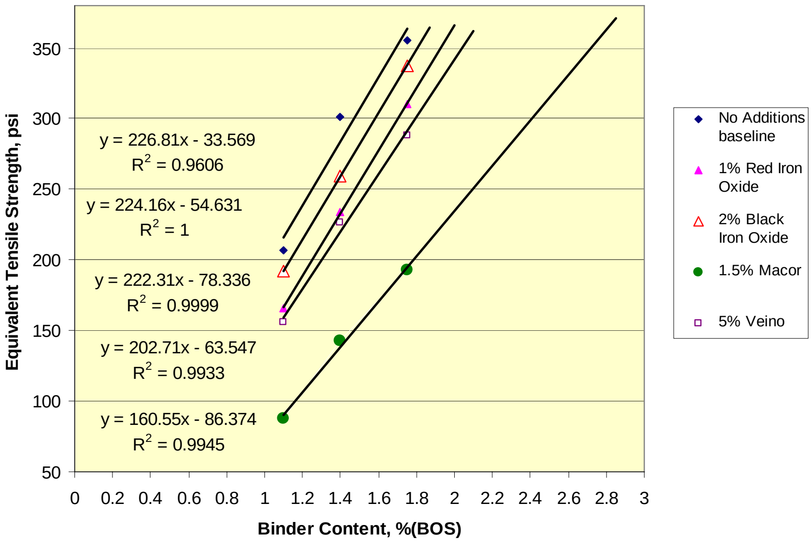

Figure 12 Average Tensile Strength of 30 Dogbone Tensile Pieces vs. Binder Content for Sands Having the Listed Anti-Veining Compounds Added.

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6.0 Section 3 casting Surface Finish Comparisons

The step core castings produced during the emissions testing were examined for surface finish and veining. Twenty castings (5 molds; 4 castings per mold) were produced for each test condition. It should be noted that these castings were all produced with 1.4% binder and no attempt was made to adjust the binder level to compensate for loss of strength due to the additives. The observations made with respect to the casting surface are specific to this particular condition. The quality of the casting should improve when the binder level is adjusted. Since this experiment was focused on measuring emissions, it is understood that the casting surface finished may not be totally representative. The castings were arranged in rank order sequence from the best to the worst based on visual assessment. A one to ten scale was also established with 10 representing the best casting and 1 representing a casting with very poor quality. Each individual group was ranked, then the five groups were examined concurrently, Table 9 is a summary of all of these comparisons. The examiners noted quite a bit of spread with respect to the surface condition of these castings. The exception was the aluminum silicate group, which were fairly close together. For this paper, the median ranking along with the overall quality number will be used to discuss the respective performance of the different additives tested. The best castings with respect to both veining and surface finish were produced using the blended material. Red iron oxide was second in overall quality. It exhibited a significant reduction in veining, but tended to produce a rougher

Table 9 Comparison of Core Quality and Anti-Veining Additive Used

Urethane Cores @ 1.4% Resin with Anti-Veining Core Additives					
Qualitative Appearance Scale*	**Reference No Additives**	**Red Iron Oxide**	**Black Iron Oxide**	**Aluminum Silicate**	**Blended Material**
10		Best			Best
9			Best		Med Best
8		Median			
7	Best			Best	
6		Worst		Med Best	
5	Median				
4			Median	Worst	
3			Worst		
2	Worst				Worst
1					

* Overall casting appearance - 10: Best, 5: Median, 1: Worst

surface finish. The castings produced with aluminum silicate ranked third in overall surface condition; both the severity of the veining and the surface finish was better than the control, but only mid-range with respect to the appearance numbers. Black iron oxide produced castings with less veining than the control, but exhibited poor surface finish. While .the binder content was not adjusted, the castings produced with additives were all better than the control. This fact becomes relevant in establishing that the level of additives used for these trials were within an effective range for this casting application.

The test results are shown qualitatively in Table 9 and Figures 13 through 17.

Figure 13 Median Appearing Casting from Mold FT001 – Aluminum Silicate

Figure 14 Median Appearing Casting from Mold FR 005 – Red Iron Oxide

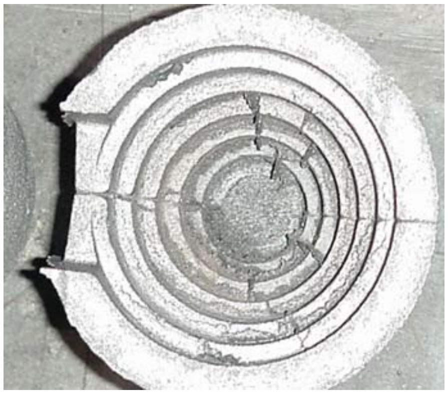

Figure 15 Median Appearing Casting from Mold FR 010 – Black Iron Oxide

Figure 16 Median Appearing Casting from Mold FR 001 – Baseline

Figure 17 Median Appearing Casting from Mold FT005 – Blender Material

7.0 Conclusion - Combined Effect Of Additives On Emissions, Casting Quality And Tensile Strength

While Core additives have been used for many years to improve core surface appearance, their effect on casting emissions had not been understood. Emission testing has demonstrated the additives selected for this test can effect the total emissions of a given system. The test data have demonstrated that some of the additives can reduce air emissions in Lbs/Lb of binder by as much as 25% from the baseline values while other additives can increase emissions. When selecting an additive package, the foundry-person must be aware of the interactions between the additives and the binder system in use, and the binder increase that may be required to maintain the needed mechanical properties. These data should be beneficial to assist foundries in selecting additives and obtaining the maximum benefit from their use. Table 10 attempts to capture all variables allowing a foundry to make choices based on knowledge of all these parameters.

Table 10 Summary of Emission, Strength and Casting Quality Attributes (1.4% binder)

Material	Measured Emission TGOC Change from Lb/Lb Baseline	Strength Change from baseline	Calculated Binder level to Maintain Equivalent Strength	Calculated Emission TGOC Change from Lb/Lb Baseline with Additional Binder to Have Strength Equal to Baseline	Median Casting Quality
Baseline	-	-	1.4%	-	5
1% Red Iron Oxide	-8%	-22%	1.63%	7%	8
2% Black Iron Oxide	2%	-14%	1.50%	9%	4
5% Aluminum Silicate (Veino®)	-25%	-25%	1.72%	-7%	6
1.5% Blended Material (Macor®)	-1%	-52%	2.30%	63%	9